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THE METALS

By A. FREDERICK COLLINS

THE METALS

HOW TO UNDERSTAND CHEMISTRY

EXPERIMENTAL MECHANICS

EXPERIMENTAL CHEMISTRY

EXPERIMENTAL SCIENCE

BOYS' AND GIRLS' BOOK OF OUTDOOR GAMES

FUN WITH FIGURES

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THE AMATEUR CHEMIST

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AVIATION AND ALL ABOUT IT

THE HOME HANDY BOOK

KEEPING UP WITH YOUR MOTOR CAR

MOTOR CAR STARTING AND LIGHTING

THE METALS

THEIR ALLOYS, AMALGAMS AND COMPOUNDS

BY

A. FREDERICK COLLINS

F.R.A.S.



ILLUSTRATED

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To
My Grand Nephew
VERN W. APGAR

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A WORD TO YOU

What we call civilization is a state of culture that is characterized by a relative progress in the arts, sciences and industries. Now civilization had its beginnings a million years or so ago when primordial man fashioned the first crude ax¹ by chipping it with another stone which he used as a hammer.

As time moved on half-a-million years or so to the Paleolithic, or Old Stone Age, man had so improved upon the art of making flint tools and implements that he could give them any shape he fancied, but they were still chipped and in the rough. By the end of this period he had progressed in both ideas and skill to such an extent that he could make hammers, knives, saws and various other tools of flint. He also made images of men and animals of bone and ivory and thus it was that he initiated the art of sculpture.

Came then a marked advance in the culture of primitive man and this is called the Neolithic Period, or New Stone Age, or Polished Stone Age. During this period, which included the last half of the Stone Age, he ground his tools instead of chipping them and he made more and better implements of bone and stone. Instead of the dull and sluggish-minded being that he is often pictured he did, possibly, all that modern man could do if he were given the same materials and had to work them under the same conditions.

¹ This is the *colith* and it is described in Chapter I.

Now whether it was foreordained by Nature or resulted from chance of circumstance, it so happened that Neolithic man discovered the first of the metals, and this was copper. This remarkable element, which was to again carry man forward in his quest for a higher state of material and social well being, came into his possession nearly ten thousand years ago but it did not come into general use until about seven thousand years ago because it was too soft to compete with stone.

The civilizing influence of the metal was, therefore, slow and it did not come about until ancient man had learned how to harden it by mixing it with tin or antimony. This was the beginning of the Bronze Age. Man already knew how to work stone into useful tools and ornate implements and he showed an even greater genius for working bronze, as the artifacts which have been uncovered by archæologists clearly show.

When iron was discovered the ancient metallurgist had a greater problem to wrestle with, for it was locked up in refractory ores and its high melting point made it a metal hard to cast. Hence, it did not supplant bronze until about three thousand years ago. This was the beginning of the Iron Age and it is still on, though we of the present century are living in what may be more accurately termed the Steel Age.

The way to make iron into steel and the discovery of how to make high grade steel at a nominal cost are the two chief factors that have resulted in the madding culture of the present period and which is appropriately known as the Machine Age.

There are many other metals, of course, besides

iron and its chief alloy, steel, that have furthered the arts, the sciences and the industries, not only in their pure states but also when they are mixed with other metals to form alloys, or are acted on by various chemicals when they form compounds.

All of the common metals are described in this book and so are uncommon ones, together with the alkali metals, the alkaline earth metals, the rare earth metals and last, but not least, the radioactive metals. I have also explained how metals are mined, how they are extracted from their ores, and how they are used in the various arts, sciences and industries—in a word, I have told the whole story of the metals to the best of my ability.

And now all I ask you to do is to read the book through, for to know the rise of the metals is to know the rise of the human race from the time that copper was discovered to the mighty industrial civilization of our own times.

A. FREDERICK COLLINS

CHAPTER I

THE DISCOVERY OF THE METALS

IF you were to look at the spectrum¹ of the sun through a spectroscope² that is secured to the eye end of an astronomical telescope, you would see a band formed of a number of colored lines which range from violet to red. These lines are produced by vapors that are given off by the various highly heated elements that the sun is formed of and of which ninety-one have been identified. Thus, sodium gives a pair of characteristic yellow lines, copper a pair of green lines, iron a couple of thousand violet lines, etc.

From this it must be clear that all of the elements and, it follows, the metals that we know about here below, had their origin in the sun and so when the mass of matter was thrown off by it which formed our earth, at the time the planets were in the making, it carried with it all of the metals which we now find on or in it.

BEFORE THE AGE OF METALS

The Stone Age.—To get a clear conception of how the first metals were discovered and the bearing they had on the discovery of other metals, we must go back

¹ A description of the spectrum and the spectroscope will be found in my forthcoming book, *Experimental Optics*, to be published by D. Appleton and Co., New York.

² The spectroscope was invented by Gustav Kirchhoff and Robert Bunsen in 1859.

a million years or so to the very beginning of the *Stone Age* and follow up the successive cultures of man. As you will see from the accompanying chart the *Stone Age* is divided into four chief parts, or *periods* as they are called.

Named, these periods are (1) the *eolithic period*, which comes from the Greek roots *eos* and means *dawn*, plus *lithos* meaning *stone*, or the *dawn stone period*; (2) the *paleolithic period*, from *palaaios* which means *old*, plus *lithos*, or the *old stone period*; (3) the *mesolithic period*, from *mezos*, which means *middle*, plus *lithos*, or *middle stone period*, and, lastly, (4) the *neolithic period*, from *neos*, which means *new*, plus *lithos*, or the *new stone period*.

Chart of Prehistoric Ages

Early Iron Age (from 1000 B.C. to 1 A.D.)	La Tene Epoch (from 500 B.C. to A.D. 1)	
	Hallstatt Epoch (from 1000 to 500 B.C.)	
Bronze Age (from 3000 to 1000 B.C.)	IV	
	III	
	II	
	I	
	Neolithic Period (from 12,000 to 3000 B.C.)	
Stone Age (from 1,000,000 to 3000 B.C.)	Mesolithic Period (from 20,000 to 12,000 B.C.)	
	Upper	Magdalenian Epoch
		Solutrian Epoch
		Aurignacian Epoch
	Paleolithic Middle Period	Mousterian Epoch
		(from 500,000 to 20,000 B.C.)
	Lower	Acheulian Epoch
		Chellean Epoch
		Pre-Chellean Epoch
	Eolithic Period (from 1,000,000 to 500,000 B.C.)	

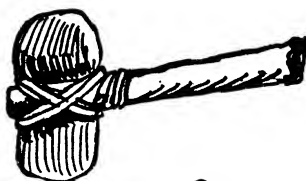
The Eolithic, or Dawn Stone Period.—This period is believed by the geologist and prehistorian to have begun about a million years B.C., and it was in this dim and distant age that the first manlike being^{*} is supposed to have made his appearance on the plains



A-An Eolith



*B-An Old Stone Age
Implement*



*C-A New Stone
Age Implement*

FIG. 1.—BEFORE THE AGE OF METALS

of Europe. Now the only evidence that this early manlike creature really lived is the shaped and chipped stones that he left behind, or *eoliths* as they are called. One of them is shown at *A* in *Figure 1*.

They are the very earliest implements that the beginnings of the human race ever made; indeed, they are so crude that there once waxed warm much argu-

^{*} He was more manlike than apeline and he is called by prehistorians the *Eoanthropus*, or *Dawn-Man*.

ment about them—whether they were fashioned by the wearing and weathering processes of nature or by the hand of a hybrid creature which was a little more than anthropoid ape and considerably less than modern man.

It is interesting to note in passing that the animals which kept this forerunner of the human race company included wild cattle, the wild horse, the bison, the giant beaver, the hippopotamus, the rhinoceros, the mammoth, and last, and most ferocious of all, the saber-toothed tiger. From the foregoing array of fauna it is clearly evident that this prehuman had to react quickly and perhaps, also, do a little thinking, if he was to survive in such an environment; and he had need of implements with which to cut up the carcasses of the beasts he killed for food and to scrape the hides he used to cover his nakedness. The eolithic period lasted for half a million years and by the end of this time the intelligence of the creature who was to become a true man had, naturally, reached a somewhat higher plane.

The Paleolithic Period, or Old Stone Age.—

This period began roughly where the eolithic period left off and it ran a course of another half million years, nearly, or more specifically, it lasted until about 20,000 years B.C. It is divided into three parts, or *epochs*, as they are called, and these are known as the *lower*, the *middle* and the *upper epochs*, respectively. By the time the eolithic period had merged into the paleolithic period the hybridized race had spread all over Central Europe and large numbers had settled down in various parts of France.

The Pre-Chellean epoch, or Strepyan epoch, is so called in the first case because it antedated the Chellean epoch, and in the latter from Strepy, which is on the River Somme in Belgium. It was at this place that the stone implements which were a shade higher than those used by the Eolithic man were first found. These implements are roughly, but definitely, flaked and usually have some part of their original surface untouched as pictured at *B* in *Figure 1*. The chief tool of the early man who made them was a hand ax which was held in the hand like a knife.

The *Chellean epoch* gets its name from Chelles, a place on the River Seine near Paris, and the implements of this culture were superior in workmanship to those of the pre-Chellean epoch as these latter were to those of the eolithic period.

The *Acheulian epoch* which followed next gets its name from Saint Acheul, near Amiens in France. The Acheulians, as the people of this culture are called, had no more implements than the Chelleans before them but their workmanship was better in that the hand axes and scrapers were thinner and more finely flaked. These three epochs form the *lower division* of the paleolithic period.

The *middle division* of this period consists of the *Mousterian epoch* and it gets its name from the cave of Moustier, in the valley of the Vézère, Dordogne, France. Now while the races that preceded the inhabitants of this epoch, which were the *Neanderthals*,⁴

⁴ So called from the Neanderthal valley in the Rhine Province, in which parts of man who lived in the paleolithic period were found.

lived on the banks of the rivers, the latter were the first to live in caves. They were a great improvement over those of the lower division for they developed a kind of language, knew how to use fire and made very fine axes and scrapers, albeit these were in the rough.

The three epochs that formed the *upper division* of the paleolithic period are known as the *Aurignacian epoch*, from Aurignac, a department of the Haute-Garonne; the *Solutrian period*, from Solutré, near Mâcon, in the department Saône-et-Loire; and the *Magdalenian period*, from the Castle of La Madeleine on the Vézère, all of which are in France. It was at or near these places that some of the various succeeding races lived and where the skeletal and cultural remains of them were first found.

Now there were two distinct races who lived in the Aurignacian period and these were (1) the *Grimaldi race*,⁵ who lived in the grottos at Menton, on the Mediterranean, in France, and (2) the *Cro-Magnon race* whose name comes from a rock shelter called Cro-Magnon that is in the valley of Vézère, in France. The Grimaldis were a dwarf Negroid race which were found at a lower level than the Cro-Magnons and it is believed they were midway between the white and black races.

The Cro-Magnons were a white race and their intelligence was such that they are called *homo sapiens*, which means *nimble-witted man*. They had bows and arrows and it is quite likely they used the latter as a bow drill which served the dual purpose of drilling holes

⁵ So named because the skeletons of this race were first found in the *Grottos de Grimaldi*.

and making fires. They were skillful when it came to drawing, painting and modeling figurines, and they were also the first to build huts to live in. From all of this, you will observe that the human race was getting well along toward a culture approximating a real civilization.

In the Solutrian epoch the descendants of the Cro-Magnon race worked bone with much skill and made and used bone bodkins that were quite like our present-day crochet needles; they also made bone harpoon heads that were barbed. They excelled, too, in making flint lance heads which they shaped like the laurel leaf, and these they fixed to the heads of poles, thus forming lances of them. Their greatest achievement, however, was the making of the flint *point-a-cran* which is the lance head with a shoulder to it and having barbed points.

Finally we come to the Magdalenian epoch which is the last one of the paleolithic period of the Old Stone Age. Like the other epochs it is named after the place where the remains of the race which belonged to it were found—near the Castle of La Madeleine in the Vézère Valley in France. Their culture was higher than that of the Solutrian epoch and they left behind the finest examples of art and artifact⁶ of the Old Stone Age. And then something happened that prehistorians have not been able definitely to explain away, for their methods seem to have been lost and with them the reindeer, the mammoth and the woolly rhinoceros completely vanished. But fortunately man himself still

⁶ This word means a simple product of aboriginal workmanship.

carried on. This is the reason that the next sequence of time is called a period rather than an epoch.

The Mesolithic, or Middle Period.—This period lasted from 20,000 B.C., to 12,000 B.C., and the peoples who lived during this time are called *Azilians*; this in virtue of the fact that their cultural remains were first found at Mas d'Azil, a place near Lourdes in the southwest of France. The larger animals having disappeared, the Azilians did many things differently from their predecessors, the Magdalenians, but what they did was scarcely an improvement over those of the older order.

The outstanding feature of their existence is the so-called *painted pebbles*. These are more or less flat stones a couple of inches in diameter which have characters painted on them in red and black. Some of these characters are curiously like the early Roman letters but what they were used for is not known, though it is thought they were employed as tallies for keeping count. They also left behind the *kitchen middens*, or *shell heaps*, and in these refuse piles have been found the shells of edible mollusks, the bones of animals and fragments of things that were baked. Implements of horn, bone and stone have also been found and evidences that they mined flint have been uncovered.

The Neolithic Period, or New Stone Age.—The beginning of modern civilization was due to the intelligence of the peoples who thrived in the neolithic period from 12,000 B.C., to 3000 B.C. These New Stone Age races were the first to plant seed and to use the ox and horse as beasts of burden. They made pottery and cooked the flesh they ate; they invented

plaiting and weaving and made nets and baskets; they contrived the dugout boat, invented the wheel and built houses, and, finally, they practiced medicine and surgery; but still all of their implements were of stone.

Different from their mesolithic ancestors the neolithic artisans often used volcanic glass,⁷ which is much harder than flint, for their implements, and they polished them instead of chipping and pecking them. The

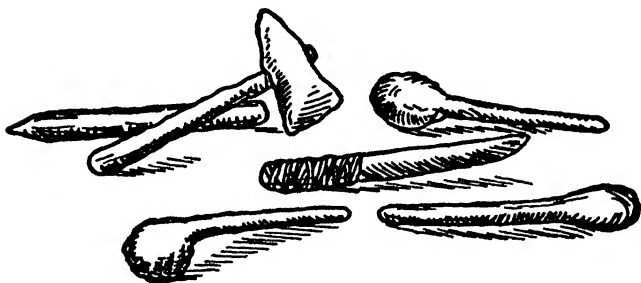


FIG. 2.—SOME IMPLEMENTS OF THE STONE AGE

way they did this was to roughly trim the glass to the size and shape they wanted it to be when finished and then ground it down by rubbing it on, or with, a stone, using the while a plentiful supply of water just as you do when you sharpen your knife on a whetstone.

While they used a drill for making small holes, they made the larger ones by boring them out with a hollow stick or bone which they rotated between the palms of their hands, the cutting element being sand and water. In this way they were able to bore a goodly sized hole through a stone ax and into which they drove the end

⁷ This is known as *obsidian* and also *rhyolite*.

of a wooden handle, as shown in *Figure 2*, thus making a powerful tool of it. Taken by and large, neolithic man was inventive and, it follows, progressive, and he did everything that was humanly possible to do with the materials he had to work with. To do more he must needs have something better than stone to make his tools and implements of and since he was ready for it, it was given to him in the form of the *metals*.

THE AGE OF METALS

The Discovery of Copper.—The first metal which neolithic man discovered was the heavy, reddish ore that we call *copper*. Now various guesses have been made by different prehistorians as to how he first obtained it and two of the most likely ones are these:

(1) That he found pieces of it in its pure state, or *native* as it is called, either in lumps on the surface of the ground or in stones that he broke apart, and (2) that he picked up a lump of copper ore, such as copper carbonate,^s and either (a) threw it by chance into a hot fire which melted the copper out of it and he afterwards found it in the ashes, or (b) that he used the lump of ore as one of the stones to inclose his fire and that this had somehow gotten into it; the heat then *reduced* the ore, that is it separated out the copper from the nonmetallic elements of which it was composed, and he found it in the ashes.

When he glimpsed the bit of copper his trained eye saw that it looked different from an ordinary piece of burnt stone and so he picked it up. He found that it was heavier than stone and altogether unlike any other

^s This is an ore called *malachite* that is found in nature.

material he had ever come across before. It intrigued him and created the liveliest curiosity and interest in those of his tribe. Being nimble-witted men they made a few primitive experiments with it and it is easy to believe that the first test they applied to it was to try to bite it (see *Figure 3*); while they were able to indent it with their powerful teeth it would not break as



FIG. 3.—THE DISCOVERY OF COPPER

would a stone of equal size. The next trial was, doubtless, an attempt to break it by laying it on a stone and striking it blow after blow with one of their stone hammers. And what must have been their surprise when instead of breaking into bits it simply flattened out and was as hard as it was at first!

The discovery, which was one of the greatest of all times, prehistoric, ancient or modern, was probably made somewhere in Cyprus where copper was plentiful.

Later on this country was destined to become famous for its *Cyprian copper*.^{*} The finding of copper, however, did not work an immediate change in the culture of the neolithic peoples any more than the finding of radium has revolutionized the culture of the twentieth century; but the latter like the former had undreamed of possibilities.

The chief reason that copper did not find immediate favor with the neolithic peoples as soon as it was discovered was because it was too soft to be used for tools. The first use to which it was put, therefore, was the making of personal ornaments. The discovery of copper is believed to have been made about 7000 B.C., and the earliest date at which its use can be fixed with anything like certainty is about 5000 B.C. when artifacts were made of it and these have been uncovered in both Chaldea and in Egypt.

The Bronze Age.—As I have intimated above, in order for copper to take the place of stone for implements it must have a hardness that is comparable with the latter material. Now, curiously enough, the copper that was obtained from the ore which was found in some places was much harder than that which came from other places. Although the early workers in the bronze age well knew that this was so what they did not know was why it was so. Later on it was found to be due to the fact that it had either a little antimony or tin mixed with it. Thus in Hungary the copper ore which is mined there also contains antimony, while in China,

^{*} The copper mines of Cyprus were among the first, if indeed they were not the first, of ancient times. They have, however, long since been worked out.

England and some other countries, the copper ore contains a small amount of tin.

Now when either antimony or tin is mixed with copper they form an alloy called *bronze*. This hybrid metal is not only considerably harder than either of the metals that go to make it up but it melts at a lower temperature than does copper alone. Moreover, the early Bronze Age metallurgist found that some of the bronze he worked was very much harder than others and in seeking a cause for this he discovered that when antimony was mixed with copper the resultant alloy of bronze that he made was not nearly so hard as when he used tin. It was not, however, an easy matter for him to distinguish the difference between antimony and tin and as the former metal is the most plentiful the bronze he produced was usually of an inferior grade. But he kept on trying.

Finally, when tin was mined in sufficient quantities so that it was used to the exclusion of antimony for making bronze, it was further found that sometimes the latter was comparatively soft and at other times quite hard. This led to more experiments with the result that it was learned that the hardness depended on the relative proportions of the copper and the tin which were used. The proportions that give the hardest bronze were found to be about 90 per cent of copper and 10 per cent of tin.

As time moved on apace in the Bronze Age special furnaces that were shaped like a crucible and lined with clay were used to smelt the ore. Layers of charcoal, firewood and ore were laid up in alternate beds and then the fire was started; when the mass was in-

tensely heated water was thrown on it and the melted copper ran into lumps when it was separated out from the slag.

When tin was first used as a separate metal to make bronze with, it was, in all likelihood, picked up from the gravel of streams but after awhile it was obtained from its ore or *tinstone*¹⁰ as it is commonly called, which was reduced in much the same way as copper ore was. This method of reduction was then improved upon by making a vertical hole in the side of a steep bank so that a chimney-like furnace was formed and the charcoal, firewood and ore were laid up in beds in it. When the fire was made the hole provided a good draft, and, it follows, a very hot fire was produced.

The Bronze Age lasted from 3000 B.C. to 1000 B.C. This sequence of time has been divided into four periods by the more recent prehistorians and each of these showed a marked advance in the art as against the one that preceded it. Different, however, from the Stone Age, the divisions of the Bronze Age are not named from the places where the advanced cultures were first found, but they are simply characterized by the Roman numerals *I*, *II*, *III* and *IV*, as a reference to the chart in the beginning of this chapter will show.

The Bronze Age reached the European neolithic peoples about as follows: Italy in 2500 B.C., France in 2000 B.C., Spain in 2000 B.C., Germany in 1800 B.C., England in 1800 B.C., and Russia not until 300 B.C. From this it is clear that the Bronze Age was introduced into these countries either by bronze implements passing from hand to hand or, and this seems more likely, by

¹⁰ The scientific name of this ore is *cassiterite*.

traders who carried the new metal implements up through Europe from the south or southwest from the place or places where it originated.

There were two main trade routes along which the primitive traders from the more civilized Mediterranean centers of the Bronze Age traveled to reach the less cultured races of the north who were yet in the neolithic age. The first of these was by the way of what is known as the *Dolmen route* and this led them through Italy or Spain, to France and thence on to England, Wales and Ireland.

The second or *Elbe route* took them through northern Italy, thence Switzerland, Hungary, Germany, Denmark to the south Baltic countries. It was in this manner, then, that in the course of a few hundred years after the discovery of bronze it found its way into every country of Europe and practically supplanted the use of stone for the fabrication of implements.

The Iron Age.—After the Bronze Age had come in other metals including iron, lead, silver and gold were discovered. Indeed, it has been thought by some authorities that gold was known before copper for prehistoric Irish ornaments made of it have been found along with those of amber and jet. Again it is believed by some that iron was known before either copper or gold. But even if these premises are true they served no useful purpose for both of these metals were not only very soft but they were exceedingly rare. While gold occasionally occurs free, the only free iron to be had in lumps is that which is found in meteorites and these were and are few and far between.

The reason, probably, that iron did not precede

bronze¹¹ is that it has a higher melting point than the latter and until man knew how to make a fire that was hot enough to reduce it from its ores he could not make use of it. Iron did not come into use until about 1000 B.C., and into general use some 500 years later. The Iron Age is, therefore, reckoned to have begun about 1000 B.C., and it is still on, although we of the present time are living in what may be more properly called the *Steel Age*.

Now when iron is pure it is almost as soft and malleable as copper but all of the iron that is obtained by smelting iron ores has a small percentage of carbon and other impurities in it and these tend to make it hard and brittle.¹² This is the reason the iron that was obtained in the ancient days could be used for tools and implements which were superior in every way to those made of bronze.

The Early Iron Age is divided into two epochs and these are known as (1) the *Hallstatt epoch*, and (2) *La Tene epoch*. The former is so-called from Hallstatt in the Nordic Alps of the Austrian Tyrol, and it ran a course from 1000 B.C., to 500 B.C. At this place there have been found bronze implements of the latter part of the Bronze Age and iron implements of the very beginning of the Iron Age.

The latter, or *La Tene epoch*, is the second half of the Early Iron Age and it gets its name from an old settlement built on piles called *La Tene*, or *The Shal-*

¹¹ As a matter of fact, iron was the first metal known and used in Central Africa and, it follows, the latter never had a Bronze Age.

¹² These properties of iron and their causes are gone into in *Chapter II*.

lows, which is near Marin, in Switzerland. The iron implements that have been found there are typical of those made during the time period between 500 B.C., and A.D. 1.

CHAPTER II

THE COMMON METALS

By the term *common metals* is meant those which, as a rule, are (1) the most plentiful in nature, (2) the cheapest, and (3) the most widely used. Of course *iron* is in the vanguard for it is, next to aluminum, the most plentiful, it is the cheapest, and, by all odds, the most useful of all the metals. Copper, tin, zinc, lead, aluminum, nickel, tungsten, chromium and mercury follow, while antimony and bismuth tag along in the rear. With the exception of copper, zinc, lead, aluminum and mercury, which find a more or less extended use in their free or elemental states, the others, including iron, are employed in the industries only when alloyed with other elements and these will be explained in detail in the chapters on alloys.

Iron, the Most Useful Metal.—We get the word *iron* from the old Anglo-Saxon one of *iren* and while the root of this is not with any certainty known, it may have been derived from the ancient Sanskrit *ayas* which means *metal*. Now while the *Chart of Pre-historic Ages*, given in *Chapter I*, indicates that iron implements had their beginning about 1000 B.C., it is well known that the ancient Egyptians had used iron most effectively two or three thousand years before that time.

Thus a blade made of iron was found in one of the pyramids which had been put there some 3000 years

B.C., and it is known that the ancient Assyrians also made and used iron implements. That the ancients away back when Moses was a boy had the hardest kind of tools with which to hew out the great blocks of stone for their pyramids and other gigantic structures, as well as to chisel the statuary they left behind and cut deep hieroglyphics in the adamantine rocks, there can be no doubt.

For this reason it was long believed that they knew how to temper copper to a degree of hardness that approached our present day steel tools, but this idea has long since been exploded. What they probably did was to make iron, or rather *steel*, which is iron with carbon in it, into tools and temper them just as we do now. So, then, it was the art of making steel and tempering it that was lost for a couple of thousand years and not the art of tempering copper.

The Romans made and used both wrought iron and steel—the former for all ordinary purposes and the latter for tools and edged weapons. When Julius Cæsar invaded Britain in 55 B.C., he found the peoples there using tools and implements made of iron, but it was not until the Roman Empire was well along that iron came generally into use throughout the civilized parts of Europe and from that time on its employment became more and more widespread.

Origin of Iron.—As I mentioned in the preceding chapter, iron, along with all of the other metals and nonmetallic elements, has existed on the earth's surface ever since the latter was thrown off by the sun. It is estimated that 5 per cent of the earth's crust is formed of iron and geologists account for its coming to the

surface in this way: The great deposits of iron ore have been brought to the earth's surface by being (1) forced out of the melted igneous rock¹ when it combined with oxygen and formed the ore that we call *magnetite*; (2) deposited in beds of sedimentary rock when it combined with a different proportion of oxygen and formed the *hematite* ores; (3) laid down in beds in the ocean and combined with carbonate and formed *siderite* or *spathic iron ore*; and (4) accumulated in swamps when it is called *bog iron ore*.

Occurrence of Iron.—Pure iron, or metallic iron, or *ferrite*, as free iron is variously called, is almost as scarce as the proverbial hen's teeth, and what we call *iron* is really an alloy made of iron and a small percentage of carbon and other substances in it. The purest free iron is found in the form of minute particles in basalt rocks² such as those that make up the Giant's Causeway, Ireland. The next purest free iron is found in meteorites but this contains from 3 to 8 per cent of nickel and about $\frac{1}{100}$ of 1 per cent of copper. Iron is also found in minute quantities in many of the natural waters, in plants and as a necessary element in the blood.

All the iron that is used for industrial purposes is obtained from ores of different kinds. Practically every country on the face of the earth has large iron ore deposits and these are near enough to the surface of the earth so that they can be profitably mined. The largest iron ore mines in the United States are in the

¹ These are rocks that were produced by the action of intense heat.

² Basalt rocks are of igneous origin.

Lake Superior region and seven-eighths of all of the iron mined in America comes from these beds.

The next largest ore deposits are in the Lorraine-Luxembourg districts and these extend along the Franco-German frontier up into Belgium. A continuation of these deposits is found in England and extends from Yorkshire on the northwest to Dorset on the southwest.

The chief factors for the economic utilization of iron ore are its proximity (1) to cheap coal with which to smelt it, and (2) to industrial centers where it can be used in quantities. Although the great deposits of ore in the Lake Superior region are a thousand miles from the nearest coal mines, still it competes successfully with that which is mined elsewhere and is nearer the coal mines. This is because the most approved methods are used for mining it and the Great Lakes offer a cheap method of transporting it.

Kinds of Iron Ore.—There are five chief kinds of iron ore and these are: (1) hematite, (2) limonite, (3) magnetite, (4) siderite, and (5) pyrite ores. Hematite (Fe_2O_3), or *red hematite* as it is also called, is *ferric oxide*, that is each molecule of it is formed of 2 atoms of iron and 3 atoms of oxygen and when powdered it is red. When pure it contains 70 per cent of iron.

Limonite ($2Fe_2O_3, 3H_2O$) or *brown hematite*, is *hydrated ferric oxide*, which means that 2 molecules of the ferric oxide (Fe_2O_3) are combined with 3 molecules of water (H_2O). When pure it contains 59.89 per cent of iron.

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as its formula shows each molecule of it is formed of 3 atoms of iron and 4 atoms of oxygen. It is black when powdered, and it contains 72.4 per cent of iron. Siderite ($FeCO_3$) or *spathic iron*, as it is sometimes called, is *ferrous carbonate* and each molecule of it has 1 atom of iron combined with 1 of carbon and 3 of oxygen. The ore contains 48.27 per cent of iron when pure.

Pyrite (FeS_2) is commonly known as *fool's gold* because prospectors new at the business in the early days often found it and thought they had struck an Eldorado. A molecule of it contains 1 atom of iron and 2 atoms of sulphur. While pyrite ore contains 46.6 per cent of iron, it is generally used for the sulphur there is in it, but the iron can be obtained from its oxidized residue. The way in which these ores are reduced, that is the iron extracted from them, is told in *Chapter XI*.

Kinds of Iron.—Since iron is an element it stands to reason that there is, in the last analysis, only one kind of it. When a metal or some other element is mixed with a metal they form what is called an alloy,³ but since iron that is used for commercial purposes always has a small percentage of carbon in it, it is not considered as an alloy. Since different percentages of carbon in iron give it different properties in this sense it may be considered to be of different kinds.

Now the three chief kinds of iron are known as (1) cast iron, (2) wrought iron, and (3) steel. *Cast iron* contains from 3.5 to 4.25 per cent of carbon as

³ The exception to this is when a metal is dissolved in mercury, in which case the mixture is called an *amalgam*.

well as various small amounts of phosphorus, silicon and sulphur, and it is these impurities that make it hard and brittle. It can be melted and cast but cannot be rolled or forged.

Wrought iron contains only 0.02 to 0.03 per cent of carbon and all of the impurities in cast iron have been removed from it, but it does contain some slag. However, for all industrial purposes it is practically pure iron and it can be forged or rolled into shape but it

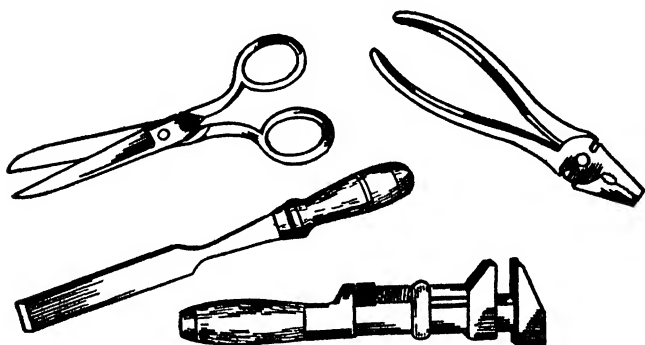


FIG. 4.—A FEW STEEL TOOLS

cannot be cast and it is not hardened when it is quickly cooled after being highly heated.

Steel is iron that has various higher percentages of carbon in it than cast iron and with all of the various impurities and slag removed from it. There are many different grades of steel and these are used for numerous different purposes as they can all be cast, forged, rolled and tempered.* (See *Figure 4*.) *Extra soft* or *dead steel* contains about 0.08 per cent of carbon and

* These processes are described in *Chapter XIV*.

this is not only very soft but ductile, malleable and tough. It can be forged and welded when cold.

Structural steel (see Figure 5) contains from 0.15 to 0.25 per cent of carbon and it is used where strength

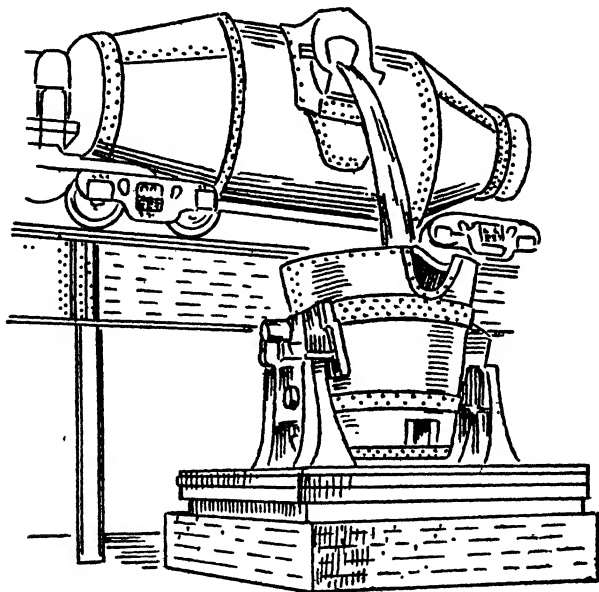


FIG. 5.—MOLTEN METAL FROM A GIANT MIXER LADLE POURED INTO AN OPEN HEARTH LADLE

This ladle car, when loaded, is the heaviest load carried on rails, weighing 325 to 350 tons. It is carried a distance of 14 miles on special tracks from Hamilton, Ohio, to Middletown, Ohio.

is needed and forging operations are necessary. For this reason it is used for *drop forgings*,⁵ buildings, bridges, boilers and railway rolling stock. *Medium steel* is harder and stronger than structural steel and it contains from 0.25 to 0.35 per cent of carbon. *Hard*

⁵ Steel that has been forged between the dies of a drop hammer or drop press.

steel contains from 0.65 to 0.85 per cent of carbon and it must be *heat treated*⁶ before it is used. After this operation wood cutting tools, steel wheels, locomotive tires, etc., are made of it.

Spring steel contains 0.85 to 1.05 per cent of carbon and it must also be heat treated after which it is very hard, resilient and brittle. It is used for the blades of shears, cold chisels, rock drills, automobile springs, etc. *High carbon steel* contains 1.05 to 1.20 per cent of carbon and it, likewise, must be heat treated. It is used for springs on railway engines and cars and for forgings and metal cutting tools. Finally, *steel alloys* are those which have other metals mixed with the steel and you will find these described in *Chapter XI*.

The Physical Properties of Iron.—Pure iron has a silver-white luster, a specific gravity of from 7.86 to 8.14, and it is not only very malleable but ductile as well. With the exception of cobalt and nickel it is the most tenacious of all the metals and it can be rolled so thin that a sheet of it will weigh less than one of the same size made of paper. It becomes soft when heated to redness and it can be welded when it is brought to a white heat, but if it is heated to a higher temperature than this it becomes brittle.

At ordinary temperatures it is strongly attracted by a magnet or other source of magnetic energy and, it follows, it is itself strongly magnetizable, but as soon as the magneto-motive force is removed it loses its magnetism. When it is heated above 760 degrees *centigrade* it also loses its magnetic properties. Oppositely

⁶ This process is described in *Chapter XI*.

disposed, when steel is magnetized it retains its magnetic properties indefinitely.

Since the physical properties of iron change when it is subjected to varying temperatures, it was long ago believed and recently proved that it has *allotropic forms*, which means that its atoms take on different arrangements according to the degree of heat that is applied to it. There are three of these allotropic forms and these are known as α -ferrite, or *alpha iron*, δ -ferrite, or *beta iron*, and γ -ferrite, or *gamma iron*.⁷

When iron has a temperature below 767 degrees it is stable and magnetic and this is the form that is known as α -ferrite. At a temperature above this point it is still stable but loses its magnetic properties and at 900 degrees it recrystallizes and shrinks $1\frac{1}{2}$ per cent in volume and it then becomes δ -ferrite. When a temperature of 1400 degrees is reached it changes back again to the stable nonmagnetic form and this it retains between the above temperature and its melting point which is 1530 degrees *C*. When the iron reaches this temperature and melts it takes on an entirely new set of physical properties.

The Chemical Properties of Iron.—The symbol for iron is *Fe* and its atomic weight is 55.84. Pure iron is not as chemically reactive as that which contains other elements. Thus pure iron will not rust, that is combine with oxygen to form iron oxide (Fe_2O_3) in air or cold water but ordinary commercial iron will do so. Iron will burn in oxygen, and when heated it will react on steam and in both cases produce

⁷ Alpha, beta and gamma are the first three letters of the Greek alphabet.

magnetic iron oxide (Fe_3O_4). While ordinary rust will not protect the surface below it magnetic iron oxide will and this is the way that *Russia iron*, which is used for stovepipes, is made.

Iron will burn in sulphur and small iron objects such as watch hands, buckles, etc., can be given a coating which will protect them from rusting by dipping them into melted saltpeter. Iron dissolves in dilute acids of nearly every kind and sets free the hydrogen that is in them. Pure hydrogen is made by dissolving iron turnings in dilute sulphuric acid. It also dissolves in cold concentrated nitric acid but does not react with fuming nitric acid.

After it has been dipped into the latter it takes on what is called the *passive state* and this is an inactive condition. Thus after it is dipped into the latter named acid, if you will then dip it into a solution of copper sulphate, it will *not* become coated with metallic copper as it is when it has not been immersed in the acid. But if you scratch the surface of it or strike it when in the passive state and then dip it into the copper sulphate solution, the copper in the latter will be deposited on it, which shows that its reactive condition has been restored. Although cobalt, nickel and some other metals also exhibit the passive state, just what causes it is a chemical mystery. Finally, iron combines directly with chlorine, iodine, bromine and fluorine all of which belongs to the halogen family.⁸

⁸ For a description of this charming family see my book *Experimental Chemistry*, published by D. Appleton and Company, New York.

Copper, the Electric Metal.—This metal came by its name in a rather degenerate fashion. Originally it was called *aes Cyprium* from these Latin words which mean *from Cyprus*, since it first came, at least in quantities, from the Isle of Cyprus in the Mediterranean. This name was then abbreviated to *cyprium*, this in turn to *cuprum* and this the Anglo-Saxons changed to *copper*.

It got its fame from the Greek goddess Aphrodite^o who chose it for her mirror so that she might take a look now and then at her pretty self—a habit that is still in vogue among her sex. I have called it the *electric metal* because it is the only cheap one which makes it possible to transmit electricity economically and, it follows, it is second only to iron in keeping up our high-powered civilization.

When the Romans conquered Gaul, Spain and Britain they found that these countries had copper deposits and from that time on to the end of the Roman Empire these were mined and the metal shipped to Rome. At about this same period and perhaps at an earlier date the American Indians used the free copper that abounds in the Lake Superior region and in the seventeenth century these deposits were discovered by the French explorers.

Copper that came from Connecticut, New Jersey and Pennsylvania was mined in the eighteenth century and small quantities of it were shipped to Europe, but it was not until the middle of the nineteenth century that it was mined in large quantities and the United States has ever since remained the largest producer of it.

^o The Romans called this goddess *Venus*.

The Origin of Copper.—The deposits of copper that are found free had their origin in the cysts, or *amygdules*, as geologists call the small spherical cavities in volcanic rocks. The metal was deposited in them by the water vapor which was set up in the molten masses.

As a matter of fact, all of the great copper deposits in various parts of the world were produced chiefly by the action of heated water and steam that were released by volcanoes. Thus the *metamorphic deposits*, as certain kinds of copper ores are called, were the result of changes in rocks caused by the recrystallization of the elements of which they were formed, and these, as well as the *limestone deposits* of ore were brought about by the action of heated water and pressure.

The *disseminated deposits*, which mean scattered deposits, are those contained in *schists*, that is rock whose structure has been sheared. This took place in the very earliest geological age, or *Archæan* period, as it is termed.

The Occurrence of Copper.—This metal is found in exceedingly minute quantities in various waters and soils, in plants, eggs and meat, in the feathers of birds, and in the blood of man and other animals including the cuttlefish. It is often found free and this the miner terms *virgin copper*. The largest deposits of free copper are those near Keweenaw, Michigan, on Lake Superior, and some of the pieces of it weigh in the neighborhood of 400 tons. It was here that the American Indian pounded off enough to make his ornaments and implements.

The world's supply of copper is, however, obtained

from its various ores and the richest of these deposits is in the Butte district in Montana, where there is a vein $1\frac{1}{2}$ miles wide and 2 miles long. There are also rich deposits on the Michigan shore of Lake Superior and also in the Globe, Bisbee, Miami and Ray districts in Arizona. In the southeast corner of Tennessee is an important pocket of copper ore. There are also copper ore deposits in various other countries in the world including Chile, China, Japan, Siberia, the Belgian Congo and Australia.

Kinds of Copper Ore.—The principal copper ores are (1) cuprite, (2) chrysocolla, (3) chalcocite, (4) chalcopyrite, (5) erubescite, (6) tetrahedrite, (7) azurite, (8) malachite, (9) melconite, (10) covellite, and (11) argonite.

Cuprite copper (Cu_2O), or *ruby copper*, is a copper oxide and contains 57 per cent of copper. Chrysocolla ($\text{CuSiO}_3 \cdot 2\text{H}_2\text{O}$) is copper silicate and contains 30 per cent of copper. Chalcocite (Cu_2S), or *copper glance*, or *vitreous copper*, as it is variously called, is a sulphur ore and contains 80 per cent of copper. Chalcopyrite (CuFeS_2), or *copper pyrite* is a copper-iron sulphide and contains 34.6 per cent of copper. Erubescite (Cu_5FeS_4) is commonly called *bornite*, *peacock copper* and *horseflesh*, and it contains 56 per cent of copper.

Tetrahedrite ($3\text{Cu}_2\text{S}, \text{Sb}_2\text{O}_3$) is a copper antimony sulphide and contains from 30 to 50 per cent of copper. Azurite ($2\text{CuCO}_3, \text{Cu}(\text{OH})_2$) is blue carbonate of copper and it contains 30 per cent of copper. Malachite ($\text{CuCO}_3, \text{Cu}(\text{OH})_2$) is a green carbonate of copper and contains 48.67 per cent of copper. Covellite (CuS) or *indigo copper* is cupric sulphide, and it contains 70 per

cent of copper, and, finally, argonite (Cu_3AS_4) is cupric arsenic sulphide and it contains 40 per cent of copper. How these copper ores are smelted and refined is explained in *Chapter XIV*.

The Physical Properties of Copper.—The specific gravity of copper is 8.29 to 8.93. It has a reddish-

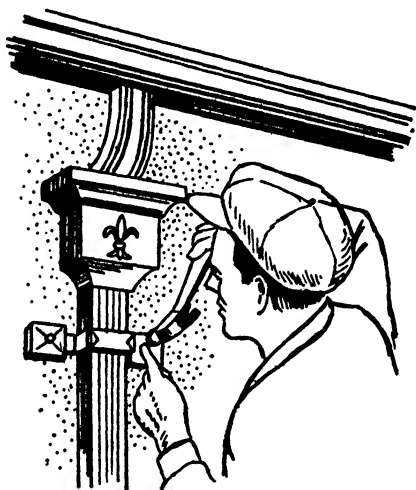


FIG. 6.—A COPPER RAIN PIPE

yellow color when it is polished and a yellowish tinge when it is freshly fractured. It appears to be red by reflected light; when hammered very thin and viewed by refracted light it takes on a greenish color and when melted it has a sea-green color. It is very ductile and it can be drawn into wire that is only 0.2 millimeter¹⁰ in diameter when a steel plate is used, or 0.3 millimeter when a diamond is used. Next to silver, copper is the best conductor of electricity and after it

¹⁰ A millimeter is 0.3937 of an inch.

is drawn into wire it is more tenacious but less conductive. (See Figure 6.)

Its Chemical Properties.—The symbol of copper is Cu and its atomic weight is 63.57. When copper is exposed to dry air it is not affected in any way but when it is exposed to air containing carbonic acid a basic green carbonate is formed on it; this is not *verdigris*¹¹ though it is often so called. Dry oxygen has no effect on copper but in moist oxygen a cuprous oxide forms on it. While copper will attack acids with oxygen in them, it will not displace hydrogen from dilute acids.

When copper is melted it absorbs hydrogen, carbon monoxide and sulphur dioxide. In absorbing hydrogen it decomposes hydrocarbon gases, such as methane and ethane, and when the molten copper cools off and solidifies these gases are set free and it is this which makes the castings porous. Copper dissolves easily in nitric acid, boiling concentrated sulphuric acid and *aqua regia*.¹² Finally, the metal is exceedingly sensitive to poisons; thus if a copper wire contains 0.0013 per cent of arsenic it will lower its electrical conductivity by 1 per cent.

Tin, the Soft Metal.—*Its Name.*—What prehistoric man called *tin*, assuming that he had a name for it, we do not know, but the ancient Greeks called it *casiteros* and the Romans called it *stannum*. The former name has survived in *cassiterite* which is applied to the chief ore from which tin is obtained. The Roman name

¹¹ Verdigris (pronounced *ver'-di-gree*) is copper acetate.

¹² The Latin term meaning *royal water*. It is made by mixing nitric and hydrochloric acids and it will dissolve gold, platinum and other metals which will not dissolve in either acid alone.

was not definitely given to the metal until A.D. 4. The reason for this is found in the fact that a thousand years before this time it was, according to Pliny,¹³ thought to be a kind of lead.

To differentiate between them, the Romans called tin *plumbum album* which meant *white lead*¹⁴ and they called lead *plumbum nigrum* which meant *black lead*.¹⁵

We get the word *tin* from the old Anglo-Saxons and almost every modern European language has a quite similar name for it. The earliest known place that produced tin in quantity was Cornwall, England, and, hence, the ancient peoples called the British Isles, the *Tin Islands*. It was from the Cornish mines that the Phœnicians took shiploads of tin to Assyria and Egypt where it was used with copper for making bronze. Long after the Iron Age came in the Romans got their supply of tin from Cornwall and this they used, together with copper, for making bronze helmets, shields and weapons.

If you should ever go to Cornwall and are sufficiently interested in archæology, you can easily find some one who will show you the remains of the ancient furnaces where the Britons smelted their tin ore, or *tinstone* as it is commonly called. The slag that they left behind is called *Jew's attle*¹⁶ and there is a pile of it which

¹³ Pliny the Elder (A.D. 23-79), a famous Roman sailor and writer, who compiled a great work, *Natural History*, in thirty-seven volumes.

¹⁴ This name is applied to-day to lead carbonate.

¹⁵ This name is applied to-day to graphite or plumbago, a form of carbon.

¹⁶ The word *attle* means *discarded broken rock*, and the slag is called *Jew's attle* because piles of it are found near the Jews' houses in Cornwall, England.

is known to this day as *Attle Saracen*, just as if the Saracens who warred with the brave descendants of Ishmael had got the tin they used for their weapons there.

The Origin of Tin.—Free tin in the form of crystallized grains or as aggregates of them is found scattered through masses of various rock and also in the gravel of river beds. These latter have been formed by the

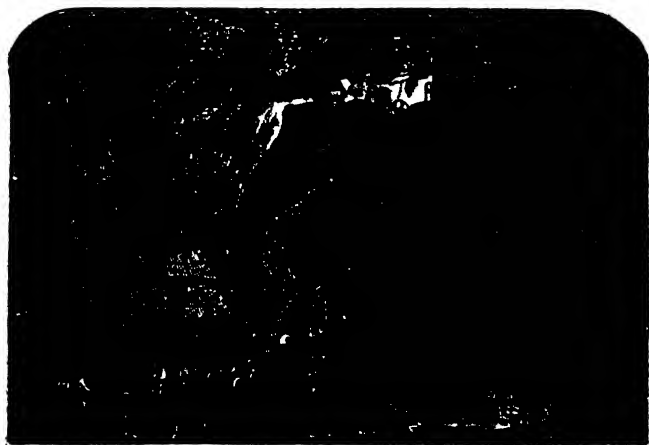


FIG. 7.—A TIN MINE IN CORNWALL
From an old print

erosion of the rocks and they are called *tin sand*, *stream sand*, *black sand* and *barilla*, depending on the locality it is found in. Free tin is also found in the silver ores of Bolivia and the gold ores of Guiana and Siberia.

Free tin and tin ores had their origin in the older granite and the volcanic rocks of the same kind, the alluvial and gravel deposits being of a secondary nature. Vein deposits, which are called *lode tin*, are found in matrices and fissures of these rocks and they are usually

associated with fluor spar, topaz, quartz and arsenical pyrites or with silver and bismuth ores or various sulphides and other compounds.

The Occurrence of Tin.—Formerly the world's chief supply of tin came from Cornwall, England. A picture of one of the old tin mines there is shown in *Figure 7*. Now the chief supply comes from the Malay States and the next largest source is Bolivia. Tin is also obtained from the islands of Banca, Billington and Sumatra of the East Indies and also from Australia. There are small amounts of it in the various countries of Europe, in Japan, and in some states of the United States and Alaska.

Kinds of Tin Ore.—The two chief kinds of tin are (1) cassiterite, (SnO_2), or *tinstone* as it is commonly called, and (2) tin pyrites. As you will see from its formula, tinstone is a tin oxide and it contains 40 per cent of tin. Pieces of tinstone are sometimes found that are white transparent crystals and these are called *tin diamonds*. (2) *Tin pyrite* ($\text{SnS}_2, \text{Cu}_2\text{S}, \text{FeS}$) is, as its formula shows, quite a complex ore, each molecule of it being formed of copper, tin and sulphur and to this is added a molecule formed of iron, tin and sulphur. It is, obviously, a lower grade ore than tinstone and this is shown by the fact that it contains only 20 per cent of tin.

The Physical Properties of Tin.—Sheet tin is a lustrous, silver-white metal, which when it is cast takes on a slightly blue tinge, dull or iridescent according to the temperature at which it is poured. It is so soft that you can cut it with a knife and so malleable that it can be rolled into very thin sheets which is called

*tin*foil, and it has practically no tenacity. When a bar of cast tin is bent it makes a peculiar shrill noise which is called the *cry of tin*. It does this because the crystals of which it is formed scratch against each other.

To show that it is crystalline all you need to do is to brush a little *stannous chloride* over the surface of it, when it will show patterns that look like the designs which frost makes on a window pane in winter. It does this because the smaller crystals dissolve more quickly than the larger ones. The effect thus produced is known by the French name of *moirée métallique*.

Tin is a *dimorphous metal*, which means that it exists in two different solid states: (1) the metallic state, at ordinary temperatures, and this becomes (2) a coarse gray powder at low temperatures. The first signs of this change are the spots that appear on objects made of tin. These are called the *tin-pest*. Here are two examples of the ill effects of this change: In 1851 the tin pipe organs at Amsterdam, Holland, were found to be no longer made of solid metal but of gray powder, and again in 1858 a consignment of tin was stored in the customhouse in Petrograd during the winter and later all that remained of it was a gray powder.

The Chemical Properties of Tin.—The symbol for tin is *Sn* and its atomic weight is 118.70. This metal is but very little affected by either dry or moist air but it does in time become tarnished. It is not affected by hydrogen but it displaces the latter in dilute acids. It is acted on very slightly by strong sulphuric or hydrochloric acids when these are cold, but it reacts with them when they are hot. With hot hydrochloric acid it gives stannous chloride and hydrogen. Finally, it

dissolves slowly in dilute nitric acid, and strong nitric acid converts it into stannic acid.

Lead, the Heavy Metal.—*Its Name.*—As I have mentioned in the preceding part of this chapter, the ancient Romans called both tin and lead *plumbum* and differentiated between them by suffixing the word

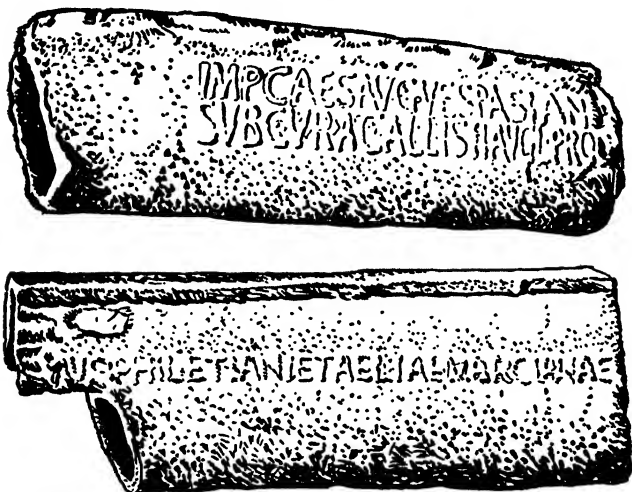


FIG. 8.—LEAD WATER PIPES OF ANCIENT ROME

The upper pipe was laid in the reign of Vespasian; the lower one bears the inscription of a Roman plumbing firm.

album (white) to the former and *nigrum* (black) to the latter. We have perpetuated the word *plumbum* by using *Pb* for the chemical symbol of lead and derivations of it for the names of certain lead compounds. We get the word *lead* from the old Anglo-Saxon *lead* but where they got it from is not of a certainty known.

Lead was known to the prehistoric peoples and that it was used in Biblical times is shown by the fact that there were lead mines in Palestine, Sinai, the

Lebanon and in Egypt. The ancient Romans used it for making rings, weights, water pipes (see *Figure 8*), and tanks and statues.¹⁷ It was also widely used in the Middle Ages, and it was the chief metal which the alchemists believed could be transmuted into gold. To-day we know it as the end product of radium.

The Origin of Lead Ores.—There is very little lead that is found free but what there is of it as well as the ores that contain it were deposited in three chief ways: (1) the separate particles of it which were contained in rocks were sorted out and deposited in beds, pockets and crevices; (2) the heated waters washed them out of the igneous rocks, and (3) they were weathered out of the original ore. Nearly all of the lead that is found in the United States is sheet fillings in vertical crevices.

The Occurrence of Lead Ores.—Lead as it occurs in ores is widely distributed throughout the world. There are several lead districts in the United States and the ores are also mined in Mexico, Brazil, Great Britain, Germany, Austria, Spain, the northern part of Africa, New South Wales, Tasmania and Queensland, Australia. The largest deposits in the United States are in the Cœur d'Alene district of Idaho and the Leadville district of Colorado.

Kinds of Lead Ores.—There are three chief kinds of lead ores: (1) galena, (2) cerusite, and (3) anglesite. Galena (PbS) is a lead sulphide ore and it contains 86.6 per cent of lead. This high content makes

¹⁷ The *Colosseum* in Rome was not so named because of its huge size but from a gigantic statue of Nero that stood near one of the entrances to it.

it the most important lead ore. It usually has some silver in it as well as traces of iron, copper, zinc, antimony and arsenic. It is the kind that is found in the rich Cœur d'Alene district of Idaho.

Cerussite ($PbCO_3$) is a lead carbonate ore and this contains 77.5 per cent of lead. It is found in the Leadville district of Colorado. Anglesite ($PbSO_4$) is a lead sulphate ore and this is very poor as it contains only 24 to 42 per cent of lead and from 0.01 to 2 per cent of silver.

There are several other ores whose lead content is so small that they can scarcely be classed as lead ores. Named they are (a) poromorphite ($PbCl_2, 3Pb_3(PO_4)_2$), and this is a lead chlorophosphate ore; (b) minnetrite ($PbCl_2, 3Pb_3(AsO_3)_2$), a lead chloroarsenate ore; (c) crocoite ($PbCrO_4$), a lead chromate ore, and (d) stolzite ($PbWO_4$), which is a lead tungstate ore.

The Physical Properties of Lead.—When lead is clean it has a bluish-gray color and is feebly lustrous. It has a specific gravity of 11.4 and is so soft you can scratch it with your finger nail and cut it with your knife. It will make a bright black mark on a sheet of paper and as it was once used for marking we get the compound word *lead pencil* from it although these convenient little implements have long since been made of *graphite*. Lead melts at a very low temperature and as it shrinks on cooling it cannot be used for castings unless it is alloyed with antimony or bismuth. Finally, it is the heaviest of all the common metals.

The Chemical Properties of Lead.—The symbol of lead is *Pb* and its atomic weight is 207.20. When lead is exposed to air it forms a film of oxide on the surface

and, different from iron oxide, it protects it from further attack. Pure water dissolves lead appreciably, but if the water contains small amounts of calcium carbonate (*i.e.*, *hard water*) a protective coating of lead carbonate soon lines the inner surface of the pipes covering the water. For this reason where a *soft* water supply comes through lead pipes it should be run off before using for either cooking or drinking purposes. Lead resists the action of acids to a greater extent than any of the other common metals and for this reason it is used to make apparatus for the manufacture of sulphuric and other acids.

Zinc, the Galvanic Metal.—*Its Name.*—We get the word *zinc* from the German *zink* and this is an abbreviation of *zinken*, a name coined by Paracelsus¹⁸ in 1520. While zinc was known to the ancients they believed that it and bismuth were one and the same thing. They called both of these metals *spiauter* from which we get the word *spelter* which is now used in the trade to mean zinc that has been cast in slabs at the furnace. Paracelsus described zinc as a bastard or semimetal and even Basil Valentine,¹⁹ an alchemist who thrived a hundred years after, plainly indicates in his book *Holographia*²⁰ that he did not know it was a distinct metal.

To whom the honor is due of having actually isolated the metal is not known, but it is a matter of record that the smelting of zinc ores had begun in England in 1730,

¹⁸ His real name was Theophrastus Bombastus von Hohenheim and he was a Swiss chemist and physician. He had much to do with the application of chemistry to pharmacy.

¹⁹ His real name was Johann Tholde and he was a German chemist and physician. His writings show that he stood just about midway between alchemy and modern science.

²⁰ This was published in 1644.

while the first zinc works in continental Europe were started up in Liège, Belgium, in 1807, and the first zinc made in the United States was in 1835. I have called zinc the *galvanic metal* because of its galvanic action when it is immersed in an electrolyte²¹ with an electro-negative metal.

The Genesis of Zinc Ores.—Zinc ores are nearly always and very largely mixed with various other materials, and they are found in deposits of several genetic types. Chief among these are the ores that are found in (1) sedimentary rocks which usually contain lead and iron, sometimes cadmium and manganese, and often arsenic, cobalt and nickel minerals; (2) in veins of the ore associated with igneous rocks, and disseminated sulphide replacements of igneous rocks; (3) igneous metamorphic deposits that contain various other minerals; (4) in metamorphosed deposits that have probably been formed of any of the foregoing types; and finally, (5) residual clays.

The Occurrence of Zinc.—Ordinarily, zinc is not found free but it is reported to thus occur in minute quantities in the northwestern part of Alabama and also near Melbourne, Australia. It is, however, abundant in various ores and these are distributed throughout the world. The richest zinc ore deposits are in the Joplin district and this embraces the adjoining corners of Missouri, Kansas and Oklahoma, the Cœur d'Alene district of Idaho, and the Leadville district of Colorado. It is also mined in New Jersey, Pennsylvania and Wisconsin, and there are great deposits of it in England, Belgium, France, Austria, Hungary, Spain and Sardinia.

²¹ Any battery solution is called an electrolyte.

Kinds of Zinc Ores.—The two chief kinds of zinc ores are (1) sphalerite (ZnS) or *zinc blende*, which is a translucent zinc sulphide, and (2) calamine ($Zn_2SiO_4 \cdot H_2O$) or *zinc spar*, which is a hydrous zinc silicate. *Sphalerite* is called by the miners *mock ore*, *false lead* and *black jack* because while it looks like lead ore it does not contain any lead; it does, however, contain 67 per cent of zinc. In the early days of zinc mining zinc ores of all kinds were called *calamine* but this was finally given to the ore that has the above formula. Not so long ago it was the chief ore but it has since lost its place to sphalerite. Calamine contains 54.2 per cent of zinc.

Other zinc ores are willemite (Zn_2SiO_4) which is a zinc silicate and contains 58.5 per cent of zinc; hydrozincite ($ZnCO_3 \cdot 2Zn(OH)_2$) with 60 per cent of zinc; zincite (ZnO), or *red zinc ore*, which is a zinc oxide that has 80.3 per cent of zinc, and franklinite ($ZnFe_2O_4$) which has a variable amount of zinc in it.

The Physical Properties.—The specific gravity of zinc is 7 to 7.2. This metal has a bluish white color with a fairly good luster when polished and a high luster when fractured. When a surface that has been fractured is examined with a microscope it is easily seen that it is made up of six-sided crystals and, it follows, they belong to the hexagonal system.²² For this reason a bar of zinc will, like tin, make a crackling sound when it is bent.

Zinc is quite soft but hard to file as the particles

²² For the different systems of crystals see my *Book of the Microscope*, published by D. Appleton and Co., New York and London.

that are removed clog up the teeth. It possesses the peculiar property of being quite brittle at ordinary temperatures but it becomes malleable and ductile when it is heated to 150°C. , or so, and it can then be rolled into sheets or drawn into wire. On being heated to



FIG. 9.—A ZINC CASTING OF AN OBJET D'ART
(Courtesy of New Jersey Zinc Co.)

200°C. , or more, it again becomes brittle. (See *Figure 9.*)

The Chemical Properties of Zinc.—The symbol of zinc is *Zn* and its atomic weight is 65.13. Zinc is not acted on by dry air or oxygen at ordinary temperatures but when exposed to moist air the surface of it is attacked, and a film of grayish-white carbonate of zinc is formed on it which protects it from any further corrosion. When zinc is heated in air to a point where it is about to boil, it will catch on fire and burn with a

bright bluish-green color. The result of this reaction with oxygen is to produce zinc oxide (ZnO) which forms dense cloudlets in the air; the ancients called the latter *pompholyx*, the alchemists named it *lana philosophia*, or *philosopher's wool*, but to us moderns it is simply *zinc white*.

If you immerse a rod of pure zinc in a solution of dilute sulphuric acid the reaction between them is very slow and the hydrogen gas that is given off is so small it cannot be seen. Having made this experiment, follow it up by immersing a rod of copper, or carbon, or other electro-negative element in the electrolyte and then connect the ends of the rods with a piece of wire when the zinc will rapidly dissolve, hydrogen will be set free, zinc sulphate will be formed and a current of electricity will be set up.

Nickel, the Hard Metal.—The *Devil* has been called many names in his time but one of the most genteel is that of the *Old Nick*, or just *Nick* for short. This is, curiously enough, where we are supposed to get the word *nickel* from and here is the way it came about. The good Swedish people coined the word *Kup-pernickel* for copper and nickel when these two metals were mixed together, which was their way of saying *copper-devil* because it was supposed to be a false copper and, it follows, the Devil's own metal. Another alleged origin of the name is that it came from *Hnikill*, an Icelandic word which means a *lump* or *ball*. Nickel was discovered to be a metal by A. F. Cronstedt, of Sweden, who successfully isolated it in 1751, but it was not until T. O. Bergman, also of Sweden, found it to be an element that it was known to be a distinct metal.

The Occurrence of Nickel.—Free nickel is very rarely found but grains of it are occasionally discovered along rivers, and, after iron, it is the chief metallic element in meteorites. There are some good sized deposits of its ores in various parts of the world, the largest being in New Caledonia, and in the Sudbury District of Ontario, Canada. Other profitable deposits are those in Great Britain, Norway, Sweden, Saxony, Russia and Spain. There is very little nickel mined in the United States.

Kinds of Nickel Ores.—Nickel is found in varying amounts in different kinds of ores, the two chief ones being (1) pentandite ($(NiCuFe)S_2$) which is a sulphide of nickel, copper, and iron and has about 22 per cent of nickel in it. This is the kind that makes up the deposits of the Sudbury district and much of this is produced as a natural alloy called *monel metal*;²⁸ and (2) garnierite ($2(NiMg)_5Si_4O_{18}, 3H_2O$), a silicate of nickel and magnesium, and which contains from 5 to 20 per cent of nickel; this is the kind that forms the deposits of New Caledonia.

The other principal ores are (1) niccolite ($NiAs$), an arsenide of nickel which contains 43.9 per cent of nickel; (2) gersdorffite ($NiAsS$), a sulpharsenide of nickel with 35.4 per cent of nickel in it, and (3) pyrrhotite (FeS) which is a sulphide of iron and often contains a little nickel.

The Physical Properties of Nickel.—Nickel is a lustrous metal with a silver-white color which has a yellowish tinge, and its specific gravity is 8.8. It is very hard, malleable, ductile and tenacious, and takes a high

²⁸ See Chapter XIV.

polish. It is one of the few magnetic metals and, like iron, it loses this property when heated. It has a high melting point which varies somewhat but is about 1452°C . (See Figure 10.)

The Chemical Properties of Nickel.—The atomic weight of nickel is 58.68. This metal does not corrode in dry air and very slowly in moist air. It displaces hydrogen very slowly from dilute acids and reacts with nitric acid. It combines with oxygen to form two oxides

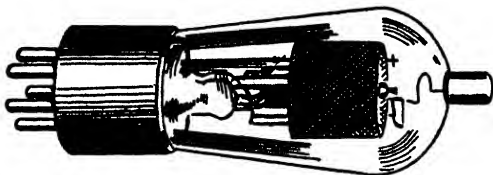


FIG. 10.—THE SCREEN GRID OF A RADIO TUBE IS MADE OF NICKEL

and these are (1) nickel monoxide (NiO), and (2) nickel sesquioxide (Ni_2O_3). Ammonium nickel sulphate ($\text{Ni}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$) is the most important nickel salt and this takes on the form of brilliant green-colored crystals.

Tungsten, the Heavy Metal.—*Its Name.*—The Swedish word for heavy is *tung* and that for stone is *sten* and there you have the origin of the name *tungsten*. Obviously, the metal was so named because it and its ores are very heavy.

Its Occurrence.—Tungsten is found free in small amounts in veins and placer deposits but its chief source is in the mineral *scheelite*, which is tungstate of calcium (CaWO_4), and *wolfram*, or *wolframite* as it is also called, which is tungstate of iron and manganese ($\text{Fe,Mn} \text{WO}_4$). Tungsten and its ores are found in

Colorado and in the Black Hills of Dakota, while Portugal and Burma are also important producers. The minerals that contain tungsten are nearly always found in tin ores and until the middle of the eighteenth century they were believed to be ores of tin.

Its History.—In 1781 the Swedish chemist Scheele showed that scheelite contained an unusual acid to which he gave the name tungstic acid (WO_3, H_2O). Then in 1783 the brothers d'Elhuyar, of Spain, proved that this acid was also contained in wolfram and by heating this mineral with carbon they were able to isolate the metal.

Its Physical Properties.—Tungsten is a bright steel-gray metal and is a very heavy one having a specific gravity of 16.6. It is exceedingly hard and brittle and has a high melting point, 3302 degrees centigrade, or 5976 degrees Fahrenheit. Tungsten is not ordinarily ductile but a process was devised by Coolidge so that it could be drawn into wire for incandescent lamps.

Its Chemical Properties.—The symbol for tungsten is *W* from *wolfram*, as it was at first called, and its atomic weight is 184.0. When tungsten combines with oxygen the oxides WO_2 , and WO_3 and W_2O_3 , which is the sesquioxide, are produced. When the trioxide (WO_3) combines with water tungstic acid is formed and when this combines with bases a series of salts result which are called the *tungstates*. Finally, when the metal combines with chlorine the chlorides WCl_2 , WCl_4 , WCl_5 and WCl_6 are formed.

Chromium, the Bright Metal.—*Its Name.*—This metal gives four distinct kinds of compounds and nearly all of them are colored. Now the Greeks used the word

kroma for color and when the metal was isolated from its compounds it was given the Neo-Latinized name of *chromium*.

Its Occurrence.—Chromium does not occur free in nature except in meteorites along with iron. It is found chiefly in various minerals, one of which is *ferrous chromite*, a mineral composed of iron, chromium and oxygen ($Fe(CrO_2)_2$). It is also found in crocoite, which is chromate of lead ($PbCrO_4$). The larger amounts of the first named mineral comes from Rhodesia and New Caledonia, while the latter comes from Siberia.

Its History.—It was first discovered by Vauquelin, a French chemist, in 1797, in a specimen of the mineral crocoite from Siberia.

Its Physical Properties.—Chromium is a very hard, brittle metal of a grayish white color and has a specific gravity of 6.8. It comes in the form of a powder, each granule of which consists of a lustrous crystal. It is a very refractory metal, having a melting point of 1520 degrees centigrade, or 2768 degrees Fahrenheit, which is higher than that of platinum. (See Figure 11.)

Its Chemical Properties.—The symbol for chromium is *Cr* and its atomic weight is 52.0. It does not oxidize in air but will burn in oxygen and when it does so it gives green chromic oxide (Cr_2O_3). Chromium produces two *chromous salts*, which are chromous chloride ($CrCl_2$) and chromous sulphate ($CrSO_4$); two *chromic salts*, which are chromic sulphate ($Cr(SO_4)_3$), and chromic chloride ($CrCl_3$); two *chromates*, both of which are derivatives of chromic acid (H_2CrO_4),

namely, potassium chromate (K_2CrO_4) and sodium chromate ($Na_2CrO_4, 10H_2O$); and, finally, the *dichromates* which are potassium *dichromate* ($K_2Cr_2O_7$) and sodium *dichromate* ($Na_2Cr_2O_7, 2H_2O$).

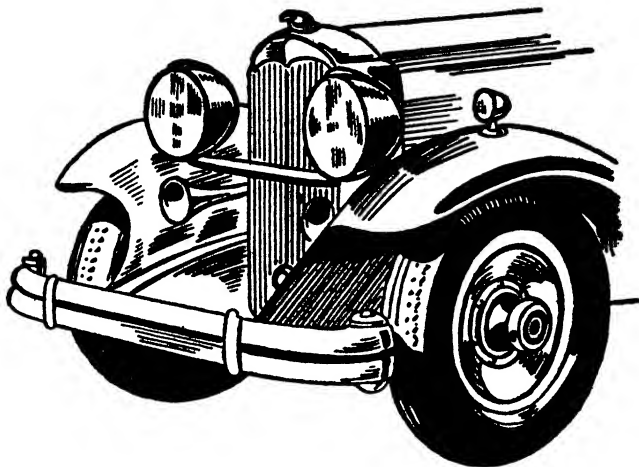


FIG. 11.—AUTOMOBILE HEADLIGHTS MADE OF CHROMIUM STEEL

The cap is made of chromium steel; the mud guards of mild steel; the hub cap of aluminum; the horn of pressed steel; and the bumpers of chrome nickel steel.

Mercury, the Liquid Metal.—While the discovery of free mercury was made in prehistoric times, there is nothing to show that primitive man made use of it. The ancient Romans called it *hydrargyrum* and this cute little name they made up of the Latin roots *hydra* which means *water* and *gyram* meaning *silver*, that is *silver water*. Some 300 years B.C., Theophrastus explained how he had extracted it from the mercurial ore called *cinnabar* by putting the latter in a copper vessel and rubbing it with vinegar, and about a hundred years later Dioscorides did the same thing by heating the ore

with charcoal in an iron pot. Pliny the Elder, who lived in the second century A.D., thought that free mercury and that which was extracted from cinnabar were somewhat different so he called the former *argentum vivum* which means *live silver* (and this is where we get the name *quicksilver*) and the latter *hydrargyrum*.

It was the alchemists who called it *mercury* after the planet of that name, for they must needs mix a little astrology with their alchemy. They swore by and at this liquid metal for they believed it was one of the components of every other metal and, it follows, they could extract the more precious metals from it—that is if they only knew how to do it.

Some of the alchemists believed it was a metal but more of them considered it to be a semimetal, and this uncertainty remained in *status quo* until 1759 when G. Braune, of Germany, solidified it by cooling it with a freezing mixture when its metallic properties were readily recognized.

The Genesis and Occurrence of Mercury.—While mercury is found free in small amounts it is contained in various ores in considerable quantities. The largest ore deposits in the world are those in the coast range district of California and the more recently discovered one at Terlingner, Texas. Europe also has profitable ore deposits, the chief ones being at Almaden, Spain; Idria, Austria, and in Voltata-Sagron and Tuscany, Italy.

Kinds of Mercury Ores.—The chief mercury-bearing ore is *cinnabar* (HgS), which is a red mercuric sulphide and contains 82.2 per cent of mercury. Other ores, or rather minerals, which contain it are (a) mon-

troydite (HgO), which is mercuric oxide; (b) mercurial tetrahedrite ($3Cu_2S, Sb_2O_3$) which, as its formula shows, is composed chiefly of copper, antimony and sulphur, but which contains some mercury; (c) coloradoite ($HgTe$), or *mercuric telluride*; tiemannite ($HgSe$) a selenide of mercury, and onofrite ($Hg(S, Se)$).

The Physical Properties of Mercury.—Mercury is a heavy white liquid metal at ordinary temperatures and it has a silvery metallic luster. Its specific gravity is

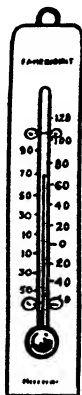


FIG. 12.—A MERCURY THERMOMETER

13.56 at $150^{\circ} C$. It will not wet glass, porcelain or other objects which come in contact with it. All of the ordinary metals, with the exception of iron and platinum, will dissolve in it. It freezes at $39^{\circ} C$., and when in its solid state it is soft, malleable and ductile. When in this condition it exhibits crystals that belong to the cubic system. (See Figure 12.)

The Chemical Properties of Mercury.—The symbol for mercury is Hg and its atomic weight is 200.61. Air does not react with mercury at ordinary tempera-

tures but if the metal is heated to nearly its boiling point it will combine with the oxygen of the former and form red mercuric oxide. This action is curiously enough reversible and when the compound is heated to a higher temperature it is decomposed and the mercury and oxygen are then set free. This is a very important reaction for it is the one which enabled Priestley²⁴ to discover oxygen.

Aluminum, the Light Metal.—In the old Roman days the physicians and dyers used a kind of a salt which they got from the volcanic deposits on the coast of the Mediterranean, and which they called *alumen*. The alchemists of the Middle Ages seemed to have overlooked this salt entirely for nothing more was heard of it until along in the eighteenth century. Then it was found that it, or a salt very like it, could be made by the interaction of sulphuric acid and clay. This salt was called *alumine* in French and *alumina* in English.

Davy believed that alumina contained a metal and in 1812 he tried to isolate it but could not do so. Nevertheless, he gave the name of *aluminum* to the then hypothetical metal. Wöhler was the first to isolate aluminum, as we call it over here, or *aluminium* as it is called in Great Britain. The way he obtained it was by heating alumina with sodium chloride with the result that the metal was separated out from the compound in the form of minute globules.

In 1854 Bunsen obtained it by electrolysis but it was a very expensive process, and the next year (1855) Deville, a French chemist, extracted it chemically and

²⁴ Priestley was an English clergyman, chemist, physicist and author who lived from 1733 to 1804.

with less trouble and at smaller cost. It was not, however, until 1886 when C. M. Hall, of the United States, discovered that aluminum oxide, which is the chief constituent of *bauxite*, an ore, could be electrolyzed in a solution of double fluoride of aluminum, which forms the mineral *cryolite*, that the metal could be made on a large scale and at a low price. Prior to the introduction of this method aluminum cost about \$5.00 per pound but the price has continued to drop until it now costs only 20¢ a pound.

The Genesis of Aluminum Ores.—There are inexhaustible supplies of aluminum in common clay and there are several explanations of how it got there. The two chief hypotheses are (1) that *syenite*, which is a volcanic rock, was first weathered to clay, or *kaolin* as it is called when it is pure, and the upper and more porous part of this was converted into *bauxite*,²⁵ which is the principal ore from which aluminum is obtained, by the waters that circulated on the surface, and (2) that the bauxite was formed by the action of hot water on the syenite.

The Distribution of Aluminum Earths.—Since clay is formed chiefly of aluminum oxide, or *alumina* as it is called, it is obvious that it is found in every country on the face of the earth; but while this is true it must, however, be obtained from some source which contains it in such a condition that it can be easily and cheaply extracted. Now the material that fulfills these requirements is bauxite and over three-fourths of it that is mined in the United States comes from Arkansas and

²⁵ So called because it was first found at Les Baux, near Arles, in southern France.

the remainder from Tennessee and Alabama. The aluminum mineral *cryolite*²⁶ or *ice-stone*, as it is popularly known, is found in Greenland as a gigantic dyke of granite.

Kinds of Aluminum Ores.—There are three chief kinds of aluminum ores and these are (1) bauxite, (2) corundum, and (3) cryolite. As I mentioned above, bauxite ($Al_2O_3, 2H_2O$), which is hydrated silicate of aluminum, is the principal ore and it contains 39 per cent of the metal. Corundum (Al_2O_3) which is an oxide of aluminum, contains 53.3 per cent of the metal, but as this ore is the hardest known substance next to the diamond, it is very valuable as an abrasive and, it follows, it is not used as a source for obtaining aluminum.

Finally, cryolite ($3NaF, AlF_3$) which is a double fluoride of sodium and aluminum, is a mineral rather than an ore as it contains only 12.8 per cent of aluminum. It is, however, used in large quantities in the extraction of aluminum from bauxite. Many gems are formed entirely of aluminum compounds with a little oxide of some other metal thrown in to give them color. Thus the *ruby* and *sapphire* are oxides of aluminum, the *garnet* is a double silicate of calcium and aluminum, the *turquoise* a hydrated phosphate of aluminum, etc.

The Physical Properties of Aluminum.—Aluminum is a silver-white metal with a bluish tinge and it takes a high polish. It has a specific gravity of 2.6, is very ductile and can be drawn into the finest wire and, next to gold is the most malleable of all the metals, while in

²⁶ This is found in white cleavable masses that have a waxy luster.

tenacity it is a close second to iron. When rolled or hammered it becomes nearly as hard as iron and, it follows, its density is increased. It is the lightest of the common metals and when struck it gives out a very clear, sweet ringing sound. It is a good conductor of heat and next to copper it is the best conductor of electricity. (See *Figure 13.*)

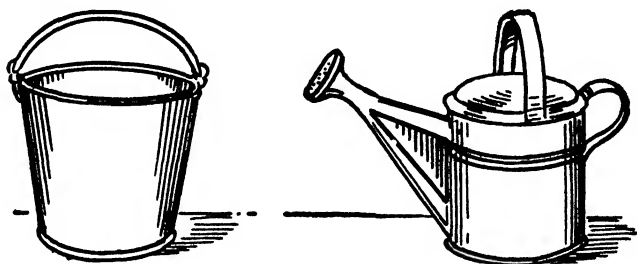


FIG. 13.—UTENSILS MADE OF ALUMINUM

The Chemical Properties of Aluminum.—The symbol for aluminum is *Al* and its atomic weight is 26.97. When aluminum is exposed to air it combines with the oxygen of the latter and the resultant compound, which is aluminum oxide (Al_2O_3), or *alumina*, forms a film on it and this protects the metal from further oxidation. When aluminum is ignited in the presence of oxygen it burns with a very bright flame and develops a very high temperature. If the metal is powdered, then mixed with the oxide of some other metal and ignited, it will burn violently and with sufficient heat to extract the metal from its oxide, while the aluminum is converted into alumina. This is the basis of the *thermite process* of welding and the extraction of metals from their oxides which you will find described in *Chapter XIV.*

When alumina is melted in an electric furnace it

forms a synthetic corundum which is called *alundum* and this is equally as good an abrasive as the natural product. As stated above when the metal is heated with a trace of the oxide of some other metal to give it the desired color, synthetic rubies, sapphires, etc., are produced.²⁷ Aluminum reacts but very slowly with cold sulphuric and nitric acid but it dissolves very quickly in hydrochloric acid.

Cobalt, the Goblin Metal.—Most of the common metals came by their names in rather curious ways but cobalt in the most curious of all, as the following goes to show. In the Middle Ages the cobalt contained in its ores was often thought to be iron and when the alchemical metallurgist tried to extract the latter—as he thought it was—from it he failed because cobalt has an exceedingly high melting point. According to his way of thinking, this untoward result was not due to his own ignorance but to an evil spirit which the Germans called *Kobold* and which was a distant relative of the *goblin* of the English. So it was for this reason, then, that when the metal was finally extracted it was called *cobalt*. The metal was first isolated by G. Brandt in 1733.

The Genesis of Cobalt Ores.—The theories which have been put forth to account for the presence of cobalt ores are the same as those already given for nickel, as these metals are nearly always found together. Moreover, when the ores are melted the two metals are

²⁷ The process of making synthetic gems is fully described in my *Experimental Chemistry*, published by D. Appleton and Company, New York.

allowed to go into the same *matte*²⁸ and are separated later on when they are refined.

Kinds of Cobalt Ores.—Cobalt is found free in very minute quantities in meteoric iron. Now it is strangely curious that the metal should not only be found associated with nickel but that its ores nearly always contain arsenic. The two chief cobalt ores are (1) cobaltite and (2) smaltite. Cobaltite ($CoAsS$) is a sulpharsenide of cobalt and contains 35.4 per cent of cobalt; while smaltite ($CoAs_2$) which is an arsenide of cobalt has 28 per cent of cobalt in it.

Other cobalt ores are linnaeite (Co_3S_4), a sulphide of cobalt, which contains 21.34 per cent of cobalt and 30.53 per cent of nickel; erythrite ($Co_3As_2O_8, 3H_2O$) or *cobalt bloom* as it is called, is a hydrous arsenate of cobalt, which carries 37.47 per cent of cobalt; cobaltarsenopyrite ($(FeCo)AsS$), or *arsenical pyrite* or *mispickel* as it is called, is a sulpharsenide of iron; it has only 6 to 25 per cent of cobalt in it and often contains nickel and gold; and finally, skutterudite ($CoAs_3$), which is cobalt arsenide and contains 88.2 per cent of cobalt.

The Physical Properties of Cobalt.—Cobalt is a silver-white lustrous metal with a slightly pinkish tinge and has a specific gravity of 8.589. It is about as hard as nickel, is very tenacious and has a high melting point. It is magnetic at all temperatures up to $1150^\circ C.$, and when this point is reached it becomes nonmagnetic.

The Chemical Properties of Cobalt.—The symbol of cobalt is *Co* and its atomic weight is 38.94. Cobalt is not affected when exposed to air or water at ordinary

²⁸ This is composed of the crude metals combined with more or less sulphur and requires further purification.

temperatures and it is only slightly oxidized by them when it is heated to redness. It is not attacked by alkali solutions but it dissolves slowly in nearly all dilute acids and reacts readily with nitric acid.

Antimony, the Expanding Metal.—Long before antimony was known as a metal the ore that we call stibnite (Sb_2S_3) which is a native antimony trisulphide was discovered by prehistoric man. Stibnite is mentioned in the Old Testament and it was evidently used by the dear young things in those early days as an all-round paint and beautifier for the eyes. Basil Valentine, the alchemist of the Middle Ages, explains the process he used to extract the metal from its ore, but as he does not say that he was the first to do so we must infer that it had been done before him.

The Genesis of Antimony Ore.—Free antimony has been found in very small amounts in various silver-lead ores. Stibnite is occasionally found in replacement deposits but generally it occurs along with quartz and calcite in veins that cut through igneous, sedimentary and metamorphic rocks.

The Distribution of Antimony Ores.—The places where antimony is found in its free state are in Sala, Sweden; Allemont in the Hautes Alps, in France, and Sarawak, in Borneo. There are deposits of stibnite in Arkansas, Nevada, California, Utah, Montana, Oregon and Washington, and also in France, Italy, Spain, Portugal, Algeria, Czechoslovakia, South Africa, Australia and China. This last named country is the largest producer of stibnite ore.

Kinds of Antimony Ores.—Antimony occurs chiefly in stibnite (Sb_2S_3) which is a sulphide of the metal,

and this is the ore that it is almost wholly obtained from. It is found to a lesser extent in various minerals as sulphides of antimony and copper, and among these are wolfsbergite (Cu_2S, Sb_2S_3), boulangerite ($5PbS, 2Sb_2S_3$), and pyrargyrite ($3Ag_2S, Sb_2S_3$).

The Physical Properties of Antimony.—Antimony is a hard, silver-white metal with a slightly red tinge. It is crystalline, very brittle and expands on cooling. It is a poor conductor of both heat and electricity. It has a specific gravity of 6.72 to 6.86. It is allotropic, that is to say there are two kinds of it, namely the *stable* kind and the *unstable* kind; the latter is known as *explosive antimony* and was discovered in 1858 by Gore, who produced it by an electrolytic process. It is so unstable that when it is scratched it explodes violently and develops a large amount of heat.

The Chemical Properties of Antimony.—The symbol of antimony is Sb and its atomic weight is 128.27. Ordinary antimony, that is, the stable kind, does not readily oxidize in air at ordinary temperatures but when it is heated in oxygen it burns and forms antimony trioxide (Sb_2S_3). When heated to redness it decomposes steam and it burns in chlorine. It combines directly with sulphur and phosphorus and when heated with various oxides of metals, such as litharge, mercuric oxide, manganese dioxide, etc., it is easily oxidized.

Dilute hydrochloric acid has no action on antimony but it reacts with warm concentrated sulphuric acid and forms antimony sulphate ($Sb_2(SO_4)_3$). Nitric acid reacts with this metal and the oxide obtained depends on the temperature and concentration of the acid. It

unites directly with the halogen family³⁹ and in many respects it reacts like arsenic in the formation of chemical compounds. (See *Figure 14*.)

Bismuth, the Brittle Metal.—The origin of the word *bismuth* is not definitely known. There are no references to it by the ancients and the first mention of it I have been able to find is that of Basil Valentine who, in 1450, called it *wismut*. Then Georgius Agricola, in 1860, or thereabouts, referred to it as *wismuth*

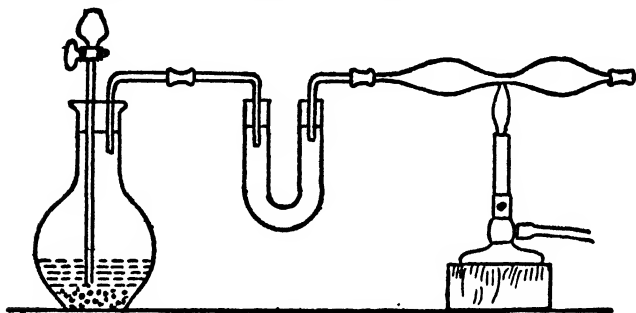


FIG. 14.—MARSH'S TEST FOR ARSENIC AND ANTIMONY

and later this was Latinized to *bismutum*. N. Geoffrey, in 1753, was the first to actually describe this metal and it was verified by Johann Potts in 1769. Finally, Olaf Bergman, about 1780, investigated its properties and ascertained its chemical reactions.

The Genesis of Bismuth Ores.—This metal is found free in small amounts in copper, lead, cobalt, silver and gold ores, and practically all of the bismuth that is used in the United States is obtained as a by-product when the ores of these metals are smelted. There are, however,

³⁹ For a description of this very odoriferous though useful putative family see my *Experimental Chemistry*, published by D. Appleton and Company, New York.

some bismuth ores that occur in veins which traverse deposits of clay, slate and gneiss.

The Distribution of Bismuth Ores.—Since bismuth is associated with other metals in their ores it follows that it is widely distributed throughout the world. The ores of the metal are found in Connecticut, California, Ontario, Mexico, Bolivia, England, Bohemia, Saxony, Norway, Spain, Rhodesia, Siberia, New South Wales, Australia, China and India. Bolivia is the chief commercial source of the supply for the world outside of the United States.

Kinds of Bismuth Ores.—The chief kinds of ores of this metal are (1) bismuthite; (2) bismutite, and (3) bismuthine. Bismuthite (Bi_2O_3), or *bismuth ochre* as it is called, is an oxide of bismuth and contains 96.6 per cent of the metal. Bismutite ($\text{Bi}_2\text{O}_3, \text{H}_2\text{CO}_3$) is a bismuth carbonate, and it has a content of 80 per cent of the metal; bismuthine (Bi_2S_3) or *bismuth glance*, is a trisulphide of bismuth and contains 81.2 per cent of the metal.

The Physical Properties of Bismuth.—This metal is grayish-white with a reddish tinge and has a specific gravity of 9.8. It is crystalline and very brittle and, like antimony, it expands when cooling from the melted state. It is a very poor conductor of heat and electricity, and is the most diamagnetic of all substances, a suspended ball of it being appreciably repelled by a magnet.

The Chemical Properties of Bismuth.—The symbol of bismuth is *Bi* and its atomic weight is 208. Dry air at ordinary temperatures has very little effect on bismuth but in heated or in moist air the reaction is

more pronounced. When heated to a bright red it burns with a bluish flame and combines with the oxygen of the air, forming bismuth trioxide (Bi_2O_3). If the trioxide is dissolved in a solution of caustic potash, and nitric acid is then added to it, a precipitate is formed and this is bismuth peroxide (Bi_2O_5). Bismuth combines directly with the halogens and also with the elements of the sulphur group.

CHAPTER III

THE NOBLE METALS

It was the alchemists of old who first called those metals that resisted the action of the air, and, it follows, retained their luster when exposed to it, the *noble metals*. Now it goes without saying that in the royal register of the metals, gold, silver and platinum headed their list, but they often included copper and mercury in it as well and later on rhodium and palladium were sometimes given a place.

Gold, the King of Metals.—Gold is a prehistoric metal and, as I have mentioned in the first chapter, it is believed by some writers on pristine metallurgy to have been the first metal ever known to man. This idea is based on the premises that (1) it is the only one of the prehistoric metals which is generally found free, and (2) that ornaments of it have been discovered which are believed to antedate anything that was made of copper.

How Gold Got Its Name.—When the early Greeks spoke of gold they called it *kloros* which means *yellow* and the ancient Romans called it *aurum* which means *greenish-yellow*. Derivations of both of these classical names are used to-day in chemical nomenclature and the abbreviation *Au* of the latter word is used as the symbol for gold. The Anglo-Saxon name for the *King of Metals* is *gold* and this, of course, is where we get the word from. I have not been able to trace it back

any further than to our English antecedents but it is more than likely that it came down to them in some degenerate way from the word *yellow*.

The Genesis of Gold and Gold Ores.—Gold is found both free and in ores. There are minute quantities of it in sea water¹ and it occurs in nearly all rocks. It exists in two forms: (1) free in sand and gravel which have been produced by the weathering of rocks that contained it, and this is known as *alluvial gold*, and (2) embedded in solid rock, when it is called *reef gold*. Gold in this form is generally encased in a matrix of quartz or *quartz lode* as it is termed.

In the alluvial deposits, or *placers* as they are called, the gold is found as (a) small rounded grains and little flakes, and this is what the miners call *gold dust*, and (b) larger masses or chunks of it which have mammillated² shapes and these are called nuggets. The largest nugget that has ever been found was the *Welcome Stranger*; it was picked up out of a rut made by cart wheels in Victoria, Southern Rhodesia, South Africa, and it weighed 2520 ounces.

The Early History of Gold.—The ancient Egyptians used large amounts of gold and they got most of it from deep mines in their own country, which they worked with slaves under the most inhuman and revolting conditions. Croesus, the richest man that ever lived, if we except Henry Ford, John D. Rockefeller, and two or three hundred other modern millionaires,

¹ There are from 5 to 267 parts of gold in 10,000,000,000 parts of water. This very small proportional amount of gold would total 10,000,000,000 tons in all of the sea water on the earth.

² That is, nipple-shaped.

had his gold mines in that part of Asia Minor where the River Pactolus flows, or as it is now called, the Baguli River. The Romans obtained much of their gold from Transylvania, then a place in Hungary, but which is now a central division of Roumania, and they also got some from the gold districts of Greece, Spain and India.

The Distribution of Gold and Gold Ores.—Gold is found either free or in ores in nearly every country on the face of the earth. After the Americas were discovered Peru, Chile, Mexico, Brazil and Bolivia supplied the Old World civilizations with practically all of the gold that was used. Then in 1848 the yellow metal was discovered in California, in 1851 in New Zealand and, finally, in 1898 the rich placers of the Klondike in Canada, and in Nome, Alaska, were opened up, when the mad rushes to these new gold outposts were made.

The last of the goldfields to become famous were those of the Transvaal, in South Africa, and these have been the source of the world's richest supplies ever since the Boers lost their independence in 1910, when the South African Republic became a British Colony. Besides the above-named places, Colorado, South Dakota, Montana, Idaho, Nevada, Arizona, and other states have rich deposits and Russia and India are also important producers of the metal.

Kinds of Gold Ores.—Gold in ores usually occurs as free gold and in this case it is mechanically mixed^{*} with any one or more of several metals, the chief ones of which are iron, copper, mercury, bismuth, silver, tellurium, palladium and rhodium. When mixed with

^{*} That is, they are not combined chemically.

silver it forms a natural alloy called *electrium*. In ores where it occurs as a chemical compound, it is generally associated with tellurium.

The three principal ores which contain gold-tellurium compounds are (1) calverite, (2) sylvanite and (3) nagyagite. Calverite ($AuTe_2$), which is a bronze-yellow telluride, contains about 40 per cent of gold. Sylvanite ($AuAgTe_2$), or graphic tellurium as it is called, is a steel gray, gold-silver telluride and this contains up to 28 per cent of gold and some silver; and nagyagite⁴ ($Au_2Pb_{14}Sb_3Te_7S_{17}$), which is a lead and gold sulphide and telluride with some antimony mixed with it, has a content of about 30 per cent of gold in it. Gold is also often associated with iron pyrites (FeS_2) and galena (PbS). Sometimes the latter ore also contains some silver and when this is cupellated, that is refined in a cupel, the small amounts of both of these noble metals are recovered.

The Physical Properties of Gold.—Gold is a very soft metal with a characteristic yellow color and brilliant luster. It is a very heavy metal having a specific gravity of 19.27. It is the most malleable and ductile of all the metals and this is shown by the fact that it can be hammered into leaf 0.00001 millimeters thick, and 1 gram of it can be drawn into a wire 2 miles long.

Its density and, it follows, its hardness and specific gravity, depends somewhat on whether it is cast or wrought, that is it is less dense, less hard and has a lower specific gravity when it is cast than when it is wrought. Gold is a good conductor of both heat and electricity, its conductivity being about $\frac{3}{4}$ that of pure

⁴ Pronounced *nod'-ya-git*.

silver. When it is brought to a high temperature it volatilizes easily and the vapor of it has a purple color.

Finally, gold can be treated by electrolysis so that it becomes very porous when it can be welded at ordinary temperatures, and in this form it is called *sponge gold* or *dental gold*. (See Figure 15.)



FIG. 15.—THE MASK OF TUT-ANK-AMEN MADE OF SOLID GOLD

The Chemical Properties of Gold.—The symbol of gold is *Au* and its atomic weight is 197.2. Gold is one of the least active of the metals and it is not attacked by air or water whatever the temperature of these may be. It will not react with either nitric, sulphuric or hydrochloric acid but it will dissolve in *aqua regia*. This is formed of 1 volume of nitric acid (HNO_3) and 2 volumes of hydrochloric acid ($HCl + H_2O$) and when these acids are mixed a reaction takes place between them and nitrosyl chloride ($NOCl$) is produced and it

is the chlorine of this which reacts on the gold. Bromine, iodine and fluorine, which belong to the same family as chlorine, i.e., the halogens, will also interact with gold and produce what is called the *gold halogen compounds*.

For many many years *aqua regia* was the only known solvent for gold but in more recent times it has been found that either selenic acid (H_2SeO_4) or telluric acid ($H_2TeO_4, 2H_2O$) will also dissolve it. So also will a dilute solution of potassium sulphate (K_2SO_4), potassium cyanide (KCN) and cyanogen bromide ($NCBr$).

What is called *fulminating gold* ($2Au(NH_3)_2 \cdot H_2O$), which is one of the discoveries of the alchemists,⁵ is a gold powder that explodes when it is struck, and it is made by precipitating gold chloride with ammonia. *Purple of Cassius* is the name given to a dye which was first prepared by Alexander Cassius and described by him in 1685. It is a purple precipitate that is made by the interaction of gold chloride with stannous and stannic chlorides.⁶ The precipitate which is thrown down is a tin oxide and finely powdered gold.

Colloidal gold consists of minute particles of gold suspended in water and it can be made by forming an electric arc between a pair of gold wire electrodes in pure water. Liquids of various colors, depending on the process of the particles, or *dispersion* as it is called, can be thus formed.

The Transmutation of the Baser Metals into Gold.—The alchemists of the Middle Ages had two pet schemes

⁵ It was described by Basil Valentine in 1644.

⁶ These are tin compounds.

and these were (1) to transmute, that is to change, the baser metals into gold, and (2) to make an elixir of life which would render the human race immune from death. While they did not get very far forward with either of these two worthy desires, the experiments they made nevertheless paved the way for modern chemistry.

The belief that the baser metals could be transmuted into gold has persisted from the Middle Ages to the present time and so various processes for the accomplishment of this mighty achievement crop up with clocklike regularity. On superficial examination, however, it is found that in every case of the alleged discovery there is a catch in it. Thus, one of the favorite schemes is the apparent transmutation of mercury into gold and, surely enough, when at the end of the operation the mercury is gone a button of gold is found to have taken its place. The result, though, could not well be otherwise for the mercury contained the gold before the alleged reaction took place and when the former was distilled off the latter was bound to remain behind.

The Latter-Day Transformation of One Element into Another.—Curiously enough, the alchemists of old were almost right in their belief that the baser metals could be transmuted into the noble ones, for the distintegration processes of the radioactive metals have shown that the transformation of one element into another is constantly going on, and the way that this is done is explained in *Chapter VIII*, under the subcaption of *Radium, Its Property of Transformation*.

The Meaning of Carat and Fineness.—The word carat comes from the ancient Greek root *karation* which means a *carob bean* that was used in the early days as a weight. The carat is still a unit of weight and is used at the present time for weighing pearls, diamonds and other precious gems. The carat is a weight which is equal, approximately, to 4 grains, but this varies in different countries. Thus in England a carat is equal to about $3\frac{1}{8}$ grains which is the weight of the *international carat* which is equivalent to 205 milligrams.

To standardize the value of the carat the *international metric carat*, or *CM* as it is abbreviated, which has a weight of 200 milligrams was adopted as the unit in the United States, Great Britain, France, Holland and Germany, in 1913.

By *fineness* is meant the proportion of gold in a mass or alloy. Thus *24 carats fine* means that the mass is 100 per cent pure gold; *18 carats fine* that the alloy has 18 parts gold in it and 6 parts of some other metal or metals in it, etc. The smallest amount of gold that an alloy can have and still be called gold is 10 parts in 24, or $41\frac{2}{3}$ per cent when, it follows, it would be 10 carats fine. The standard fineness of gold for market quotations is 900 in New York and 916.6 in Paris and this means that in the first case there is 90 per cent gold in the alloy and 10 per cent of other metals, and in the second case there is 91.66 per cent of gold and 8.34 per cent of other metals.

Silver, the Queen of Metals.—The very agreeable metal that we call *silver* was known to the ancient Greeks as *argyros* which means *shining*, and to the

Romans as *argentum*, which means *silver*. In the Middle Ages the alchemists named it *luna* after the moon because it was both white and bright. We get the word *silver* from the Middle English *selvor* and this was taken from the Anglo-Saxon *seolfor*.

The Early History of Silver.—Like copper and gold the metal silver was known to prehistoric man but it was probably not discovered by him until after he had used the two former ones. Coming down to historic times an inscription records the fact that it was used in Chaldea, some 4500 years B.C., as a medium of exchange, that is to say as money. Again the Old Testament tells us that Abraham, who lived about 2000 B.C., bought a parcel of land for a burial place and paid for it with silver.

The first actual evidence of silver that has come down to us are ornaments which have been found in the royal tombs of Chaldea and these were built about 4000 B.C. In the time of the Pharaohs who reigned in Egypt in the *IVth dynasty* and that was about 4000 B.C., and for many dynasties thereafter, gold was much more plentiful than silver and, it follows, the latter had a greater intrinsic value. By the time the *XVIIIth dynasty* had rolled around, some 2000 years later, the Phœnicians had opened up the trade with all of the Mediterranean ports and they brought silver to them in such quantities that its value dropped below gold and it then took a second place to the King of Metals.

The Genesis of Silver and Silver Ores.—Silver is found free in widely different places and under varying conditions. Thus there are minute quantities of it present in sea water and it occurs in larger amounts,

ranging from delicate threadlike bits to masses that weigh upwards of nearly a ton. The chief source of silver is, however, found in its ores in which it is combined with other elements especially antimony, copper, lead and gold.

Now there is every reason to believe that silver, like gold, was one of the original constituents of eruptive rocks and that the concentration of this metal in quantities large enough to form veins was due to the action of hot waters that flowed over the *magmatic*, that is doughy mass, of the igneous rocks as they were cooling off. Free silver is due to the weathering of these rocks while the ores that are formed of the sulphides, arsenides and antimonides are usually found at a level that is below ground water.

The Distribution of Silver and Its Ores.—Free silver and that which is in ores is found to some extent in almost every country on the face of the earth. The silver mines at Laurion in Greece, famous at the beginning of the Christian era for their large output of silver, are now worked chiefly for lead. Mexico has been known the world over for her rich silver mines almost from the time that the Americas were discovered and following it, in turn, came Bolivia, Peru and Chile.

Nearly all of the total output of silver came from those countries until about 1895 when the rich Comstock lode⁷ in Nevada became, next to Mexico, the largest producer of the Queen of Metals. The output of this productive district, however, gradually dwindled

⁷ It produced gold and silver in the proportion of 1 part of the former to $\frac{1}{2}$ parts of the latter.

and then in 1916 the great lode at Tonopah, Nevada, jumped to first place as a producer of silver in the United States. There are many other silver fields in the United States but those of Colorado, Idaho and Nevada are important producers, though not nearly as much so as those above cited.

Scattered through Europe are numerous silver districts, among them those of Spain, Norway, Austria, Hungary and Germany. In the first half of the nineteenth century the most productive mines in Europe were those of Guadalajara, Spain, and while the mines there are still being worked they are of small importance. This, also, is true of the mines at Kongsberg, Norway, and so to-day Mexico and Nevada still hold first place as the largest producers of the metal.

Kinds of Silver Ores.—The chief ores which contain large proportions of silver are (1) argentite, (2) pronsite, (3) pyrargyte, (4) stephanite, (5) cerargyrite, (6) hessite, (7) tetrahedrite. Argentite (Ag_2S) or *silver glance* as it is called, is a black sulphide of silver and it contains 87.1 per cent of silver. Pronsite ($3Ag_2S, As_2S_3$), or *light ruby silver*, has 65.4 per cent of silver in it. Stephanite ($5Ag_2S, Sb_2S_3$) or *brittle silver*, has 68.5 per cent of silver.

Cerargyrite ($AgCl$) or *horn silver*, is a silver chloride ore, and it contains 75.3 per cent of silver; it is so soft it can be cut with a knife; and tetrahedrite (Cu_2AsS_4)^{*} or *Fahlery*, or *Fahl ore*, as it is variously called, is a copper, arsenic, silver sulphide ore with base metals. As no two samples of the ore have the same composition a formula for it cannot be given with anything

* This is an approximate formula.

like accuracy and the percentage of silver in it varies.

Dyscraside (Ag_3Sb) is an antimonial silver mineral which is nearly always found in cobalt ores. Galena (PbS), our old lead sulphide friend, often contains from 50 to 200 ounces of silver to the ton and this is extracted as a by-product at a very small cost.

The Physical Properties of Silver.—Silver is a beautiful, lustrous, white metal and the most common of those classed as noble. When cast it has a specific gravity of 10.05. It is quite soft and, next to gold, it is the most malleable and ductile of the metals and takes a high polish. When silver is hammered or rolled it becomes harder but it can be made soft, or *annealed* as it is called, again by heating it to a dull red. It can be made so thin that it will transmit light which then takes on a blue color. Of all of the elements it is the best conductor of heat and electricity. It can be vaporized in the electric arc and it then has a green color.

When it is in the molten state it will absorb 22 times its own weight of oxygen from the air and it gives this out violently as it solidifies. If the molten metal is quickly cooled it tends to retain the oxygen as it becomes solid and then the expanding gas breaks through the crust and forces out particles of the melted silver. These solidify in globular form and this action is called *spitting*. It can be prevented by covering the surface of the metal with some nonoxidizing flux such as powdered charcoal, or by adding a very little zinc, copper or bismuth to the molten metal. (See *Figure 16.*)

The Chemical Properties of Silver.—The symbol for silver is Ag and its atomic weight is 107.88. Silver

is not acted upon by either dry or moist air at ordinary temperatures as it does not directly combine with oxygen (O_2), but it does, however, do so with ozone (O_3).⁹ It is not affected by the caustic alkalis or by vegetable acids. Blackening, or *tarnishing* as it is called, is caused by the sulphur (S) that is in the air which combines with the silver, forming black silver sulphide (Ag_2S). To remove the tarnish you need only to brush



FIG. 16.—TEA SERVICE MADE OF SILVER

the silver over with a dilute solution of potassium cyanide (KCN).¹⁰

Silver dissolves easily in nitric acid and forms silver nitrate ($AgNO_3$) and nitric oxide (NO) which latter is a gas. It also dissolves in hot sulphuric acid and this forms silver sulphate and sulphur dioxide which latter is a gas. It reacts with hydrochloric acid but as this produces a film of silver chloride it stops all further action. When silver reacts with nitric acid silver nitrate is formed and when this compound is melted and cast into sticks it is called *lunar caustic*.¹¹ Silver combines with all of the halogens and produces

⁹ An exceedingly active form of oxygen.

¹⁰ This is an exceedingly poisonous salt, so, on second thought, you had better let the tarnish stay on to the end that you may stay on yourself a little while longer.

¹¹ The chemical name of it is *silver nitrate*.

silver chloride ($AgCl$), silver bromide ($AgBr$), silver iodide (AgI), and silver fluoride (AgF). All of these salts are easily decomposed by light, especially the second and third ones.

What is called *molecular silver* is silver that is in a very finely divided state and this is exceedingly reactive chemically. It is a grayish powder and can be made either by precipitating it in a solution of ferrous sulphate, or some other reducing agent, or by bringing iron or zinc or some other electropositive metal into contact with one of the silver halides immersed in slightly acidulated water.

Colloidal silver, that is particles of silver which remain distributed throughout and suspended in a solution, can be formed by precipitating a nitrate of silver solution with tannin or other vegetable substance. A solution of brown colloidal silver can be made by forming an electric arc between a pair of silver electrodes immersed in pure water.

The Costly Metal Platinum.—*Platinum* in its native state is always found mixed with other metals. These are *iridium*, *osmium*, *palladium*, *rhodium* and *ruthenium*. All of these metals are chemically related to each other and so they are called the *platinum family* of metals. Thus when platinum, iridium and osmium are grouped together their atomic weights will be found to be very close to each other and this is also true of their densities. There are several other respects in which they are quite similar, as, for example, their high melting points and their resistance to acids.

How It Got Its Name.—It has been said that the Greeks had a name for everything, and I will go this

broad statement one better and say that they had names for things they knew nothing about. As an illustration of this apparent paradox, they knew nothing about platinum and yet we got the name of this metal from them and this is the way it came down to us. When a thing was *flat* the Greeks called it *platus* and from this word we get the name *plate*; the Spaniards used the Neo-Latin word *plata* for *silver* and when platinum was discovered in South America in the sixteenth century they named it *platina del Pinto*, *platina* being diminutive of *plata* and therefore meaning *little silver* and *del Pinto* a river on which the new metal was discovered. The modern chemists cut off the tail *a*, inserted *in* and added the modern Latin suffix *um* to it when they converted it into *platinum*.

The Occurrence of Platinum.—As I mentioned in the initial paragraph, platinum is, with one exception, found native, that is in its free state, but it is always mixed with other metals and in varying proportions. It is also found in small quantities in the mineral *sperrylite* which is an arsenide of platinum ($PtAs_2$). Platinum is chiefly found in the form of little rounded grains or in scales in alluvial deposits, that is, deposits which have been washed away by the flowing water of streams or rivers from one place and built up in another. Sometimes, however, nuggets of it are found that are quite large. The arsenide is the only chemical compound of platinum that is known to occur in nature.

Until about 1825, when platinum was discovered in the Ural Mountains all of it came from South America; at the present time Russia produces about 90 per cent of the world's supply, the remaining 10 per cent coming

from Colombia, Panama, several of our western states, Brazil, Peru, Australia, South Africa, Borneo and Tasmania.

Early History of Platinum.—Platinum was undoubtedly known long before it was put to any practical use or a name had been given to it, but because of its high melting point it was of very little value. The earliest reference to it that I have been able to find is one in which Scalinger, who lived in the sixteenth century, tells about a metal that is found in the mines of Mexico and Colombia, then called Darien but now the Republic of Panama, whose melting point was so high it could not be used.

It was not until about 100 years after Scalinger reported his find that the chemists of Europe became interested in the new metal and Scheffer, of Sweden, read a paper before the Stockholm Academy in 1732 in which he called it *white gold*, or the *seventh metal*, or *platina del Pinto*, as the Spaniards named it. Then in 1750 Sir William Watson of England described it in the *Philosophical Transactions*.

Scheffer showed, in 1752, that the best furnaces of his time could not develop a sufficiently high temperature to melt it, but a quarter of a century later Macquer and Baume fused it by concentrating the sun's rays on it with a powerful burning glass, i.e., a convex lens. Finally, in 1772 Count von Sickingen, of Germany, rolled the metal into wire and sheets and it then took its place among the useful metals.

The Physical Properties of Platinum.—In its ordinary condition platinum is a metal that has a color just about like that of steel. It has a specific gravity of

21.4 and is therefore appreciably heavier than gold, whose specific gravity is 19.27. It melts at about 1755 degrees centigrade but it can be welded at red heat. It can be melted with the oxyhydrogen blowpipe or in a powerful blast furnace and it can be volatilized, that is converted into a vapor, in the electric furnace. When this is done and it condenses it crystallizes in cubic

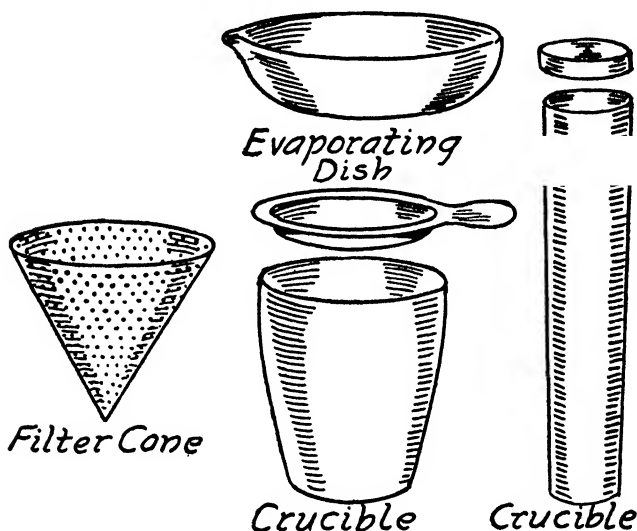


FIG. 17.—PLATINUM WARE FOR CHEMICAL WORK

and octahedral prisms. It expands less when heated than any of the other metals and its coefficient of expansion¹² is practically the same as that of glass.

When it is pure it is a very soft metal and is exceedingly ductile and malleable. Also in its pure state it is a very poor conductor of heat and electricity.

¹² This means the ratio of the increase in length, area or volume of a body for a given rise in temperature.

Platinum forms alloys with nearly all of the metals very easily but unlike the other noble metals, it has small tendency to amalgamate with mercury. When platinum is alloyed with iridium and rhodium its hardness is increased and its melting point is raised; oppositely disposed, when it is alloyed with lead or bismuth its melting point is materially lowered. (See *Figure 17.*)

The Chemical Properties of Platinum.—The symbol for platinum is *Pt* and its atomic weight is 195.23. It is not affected by the atmosphere and it is not oxidized in the air even when heated to the highest temperatures. No single acid has any effect on it when it is pure but it will dissolve in nitrohydrochloric acid,¹³ or *aqua regia* as it is commonly called. While it has a high resisting power to the action of acids it corrodes very easily when it is heated with the alkalis or alkaline earths; thus when it is heated with potassium nitrate and potassium hydroxide¹⁴ it forms platinum oxide and this combines very easily with the alkaline bases.

When platinum reacts with oxygen they form platinous oxide (PtO), and platinous hydroxide ($Pt(OH)_2$) and this latter combines with acids but not with bases, and platonic hydroxide ($Pt(OH)_4$) and this compound reacts with both acids and bases. When the metal reacts with chlorine it gives platinous dichloride ($PtCl_2$) and platonic chloride ($PtCl_4$). With potassium cyanide platinum gives po-

¹³ This is a mixture of nitric and hydrochloric acid.

¹⁴ Commonly called *caustic potash* and colloquially *potassium hydrate*.

tassium platinocyanide ($K_2Pt(CN)_4 \cdot 3H_2O$), and with barium cyanide it gives barium platinocyanide ($BaPt(CN)_4 \cdot 4H_2O$).

Chloroplatinous acid (H_2PtCl_4) and chloroplatinic acid ($H_2PtCl_6 \cdot 6H_2O$) are formed by the reaction of platinum with chlorine. Finally, when chloroplatinic acid reacts with hydrogen sulphide they form platinum sulphide (PtS) and platinum sulphide (PtS_2).

Platinum Sponge and Platinum Black—Platinum has the power to condense oxygen on its surface and to dissolve hydrogen. Platinum foil will absorb varying amounts of gases ranging from 80 to 200 times its own volume. *Platinum sponge*, or *spongy platinum* as it is commonly called, is platinum in a finely divided state and, it follows, it has an extremely large surface as against that of an equal amount of the solid metal. Platinum sponge is made by igniting ammonium chloroplatinate ($(NH_4)_2PtCl_6$).

This power of the finely divided metal to condense and absorb gases is due to the fact that it exerts a most energetic oxidizing action even at ordinary temperatures. As an example of this action, which is a *catalytic*¹⁵ one, it will ignite a mixture of oxygen and hydrogen and cause them to explode, it will oxidize sulphurous acid and convert it into sulphuric acid, ammonia into nitric acid, and alcohol into acetic acid.

Platinum black is platinum that is still more finely divided than spongy platinum and, hence, its powers of condensation and absorption of gases is greater than that of the latter. Platinum black looks like soot and

¹⁵ For an explanation of this remarkable action see my *How to Understand Chemistry* or any college textbook on chemistry.

it is made by adding zinc to chloroplatinic acid. It is this form of platinum that is used for automatic lighters for gas light burners and also for chemical reactions where a catalyst or contact agent is required.

The Metal Iridium.—*Its Name.*—This metal gets its name from the Latin word *iris*, which means *rainbow* and this came from *Irides*, the Roman mythological goddess of the rainbow. It was called *iridium* by its discoverer because of the rainbow color of its salts.

Its Occurrence.—Iridium is found in its free state in small amounts but it usually occurs with osmium in platinum ores when the alloy of the two metals is known as *iridosmium* or *osmiridium*. The chief sources of platinum ores have already been given under the heading *The Occurrence of Platinum*.

Its History.—Iridium was discovered by Tennant in 1802 when he observed that an insoluble residue was left behind when platinum was dissolved in *aqua regia*. Then in 1804 he proved that the residue was formed of two other metals and these he named *iridium* and *osmium*.

Its Physical Properties.—Iridium like platinum sometimes occurs in a spongy form or powder but it can be compressed into a solid mass. It is one of the heaviest metals known, having a specific gravity of from 21 to 22.4. When compressed it takes on a steel-white color and is harder than iron. It is brittle and not malleable when cold but is somewhat so when heated to incandescence. Its melting point is very high, being in the neighborhood of 2200 degrees centigrade, or 4000 degrees Fahrenheit.

Its Chemical Properties.—The symbol for iridium is *Ir* and its atomic weight is 193.1. It is not oxidized by either air or moisture and there is no known acid which will dissolve it. The metal has no acid-forming properties and in this respect it resembles cobalt. The oxides are *IrO*, *Ir₂O₃*, and *IrO₂* and a series of complex chlorides are formed by the reaction of the metal with chlorine.

The Metal Osmium.—Its Name.—The discoverer of this metal gave it the name *osmium* which he Latinized from the Greek *osme* meaning *odor*. This he did because its oxide gives off a strong chlorine-like odor.

Its Occurrence.—Osmium, as I have previously explained, is found chiefly as an alloy of iridium and which is called *osmiridium* or *iridosmium* and this is in the form of grains and flakes in platinum ores.

Its History.—The metal osmium was discovered by Tennant in 1802 at the same time that he found iridium in the residue that was left behind when he dissolved platinum in *aqua regia*.

Its Physical Properties.—Osmium is a blue-white metal which occurs in two different forms: the spongy form and the crystallized form. It is the heaviest substance known, having a specific gravity of 22.48. It is harder than glass and is the most infusible of the metals melting as it does at about 2700 degrees centigrade or 4900 degrees Fahrenheit, and, it follows, it can only be melted in the electric arc.

Its Chemical Properties.—The symbol for osmium is *Os* and its atomic weight is 195. In its compact form it is insoluble in all acids. It forms four oxides: *OsO*, *Os₂O₂*, *OsO₂* and *OsO₄*; the last named is the

tetroxide, a white crystalline substance which is exceedingly volatile and an irritant poison; it is called *osmic acid* but it is neither a real acid nor even an acid anhydride.¹⁶ The metal forms several compounds with chlorine the chief ones of which are $OsCl_2$, $OsCl_3$ and $OsCl_4$. Two sulphides are known and these are OsS_2 and OsS_4 , and it also gives a fluoride OSF_4 .

The Metal Palladium.—*Its Name.*—In 1802 Olbers, the astronomer, discovered a new asteroid and he named it *Pallas* after the Greek goddess *Pallas Athena*. A year later Wollaston discovered a new metal and he gave it the Neo-Latin name of *palladium* in honor of the asteroid Pallas.

Its Occurrence.—Palladium is found in very small amounts in its free state and in little larger quantities alloyed with gold and silver, and the ores of these metals are found in the Harz mountains in Germany and in Brazil. The chief source of the metal is, however, in the copper and nickel ores in Ontario, Canada, and these are capable of producing more than the present needs for it.

Its History.—Palladium was first isolated by Wollaston in 1802 and instead of making known the process by which he did it, in the usual way, that is by reading a paper before a scientific body, he put a few samples of it on the market. Chenevix, another chemist, examined one of the samples and pronounced it to be simply a platinum amalgam. Wollaston then read a paper on the metal in which he explained how he had obtained it, and at the same time announced the discovery of another new metal which he called *rhodium*.

¹⁶ This means it is not capable of forming an acid.

Its Physical Properties.—Palladium is a silver-white metal and has a specific gravity of 11.5. It is malleable and ductile and melts at 1549 degrees centigrade, or 2820 degrees Fahrenheit and this, you will observe, is the lowest melting point of all of the platinum metals. Like platinum there are two forms of the metal, and these are the spongy and the compact forms. The spongy kind has the remarkable power of absorbing gases and it will absorb nearly 1000 times its own volume of hydrogen gas.

Its Chemical Properties.—The symbol for palladium is *Pd* and its atomic weight is 106.7. It is not acted on by either air or moisture but is slowly dissolved by sulphuric, nitric and hydrochloric acids and readily dissolved by *aqua regia*. When the metal is ignited the spongy form of it is produced. It is a remarkable *catalytic agent*, that is it hastens the reaction between various chemical substances while it does not itself enter into combination, or, in other words, it remains unchanged.

There are two kinds of palladium oxides known and these are *PdO* and *PdO₂*. When the metal is dissolved in strong *aqua regia*, palladic chloride (*PdCl₂*) and chloropalladic acid (*H₂PdCl₆*) are formed. When combined with sulphur two different sulphides result and these are *Pd₂S* and *PdS₂*.

The Metal Rhodium.—*Its Name.*—The ancient Greek name for *rosy* is *rhodeos* and this word was derived from *rhodon* which means *rose*. Now the metal *rhodium* was so named because nearly all of its salts are rose colored.

Its Occurrence.—Rhodium is obtained from the residues of platinum ores and it is also contained along with other members of the platinum family in a natural alloy formed with gold in the mineral *rhodite* or *rhodium gold* as it is commonly called.

Its History.—Rhodium was discovered by Wollaston in 1803 when he was investigating the residues of platinum ores.

Its Physical Properties.—Rhodium has a silver-gray color very much like that of aluminum and its specific gravity is between 11.0 and 12.0. It is a very hard metal and has a melting point considerably higher than platinum. It absorbs gases like platinum and other members of the platinum family.

Its Chemical Properties.—The symbol for rhodium is *Rh* and its atomic weight is 102.91. It does not oxidize in air at ordinary temperatures but does so when it is heated to redness. It is not attacked by acids of any kind and has no acid-forming properties, and in this respect it behaves like cobalt. Several oxides are known, the chief ones being the sesquioxide (Rh_2O_3), and these give the corresponding salts.

The Metal Ruthenium.—*Its Name.*—The metal ruthenium was named after *Ruthenia*, a district of Russia where the first platinum ores were found.

Its Occurrence.—Ruthenium is found alloyed with the other metals of the platinum family in nuggets and little grains and crystals, and also in the mineral *laurite* which is a black sulphide of osmium and ruthenium ($(RuOs)S_2$). The chief source of the metal is the Ural mountains, but smaller amounts are found in California, Borneo, Australia and other places.

Its History.—In 1828 Osann announced the discovery of a new metal which he named *ruthenium*, together with two other new metals both of which he had found traces of in the platinum ores. Later on he came to the conclusion that he was mistaken about the existence of the new metals and thereupon withdrew his claims. In 1845 Claus investigated the discoveries of Osann and found that he was correct in his surmises as far as the metal ruthenium was concerned and he retained the name its discoverer originally gave to it.

Its Physical Properties.—Ruthenium is a dark gray color very much like iron and its specific gravity is about 12.0. It is a hard and heavy metal and has the highest melting point of any of the platinum family of metals except osmium, its melting point being about 2500 degrees centigrade, or 4530 degrees Fahrenheit. Like nearly all of the other metals of the group it readily absorbs gases.

Its Chemical Properties.—The symbol for ruthenium is *Ru* and its atomic weight is 101.7. It does not oxidize in air at ordinary temperatures and but slightly so when heated. Like osmium it resembles iron in that it combines easily with free oxygen; it forms six different oxides and these, in turn, form various salts which are quite like those of platinum. The metal gives Ru_2O when burned in air and RuO_2 when burned in oxygen.

CHAPTER IV

THE ALKALI METALS

THERE are certain compounds that are diametrically opposed to the acids and these we call the *alkalies*. These latter are formed of some of the metals when they are combined with hydrogen and oxygen and are known as *hydroxides* or *bases*. Now we get the word *alkali* from the Arabic *al* which means *the* and *qalai* meaning to *fry* and, hence, *ashes*.

In olden times *alkali* was used to mean *pot-ashes*, because when wood ashes were leached and the solution thus obtained was boiled with other compounds in an iron pot *caustic potash* as it is commonly termed, or potassium hydroxide (KOH) as the chemist calls it, was produced. It was Sir Humphry Davy who discovered that caustic potash was formed of the metal potassium and hydrogen and oxygen, and when the metals sodium, lithium, cesium and rubidium were discovered and it was found that they would also produce the hydroxides, they were all grouped together and called the *alkali metals*.

The Metal Sodium.—How It Got Its Name.—There is a kind of plant that is called *saltwort* and from time immemorial it has been used for the making of soda ash. Now saltwort belongs to the genus *salsola* and this gets its name from the Latin *sal* which means *salt* plus *sola* which means *soda*. In medieval times ~~all~~ of the alkali compounds were called soda and from

this came the Neo-Latinized name of the metal *sodium*.

The Occurrence of Sodium.—Sodium is one of the most abundant elements in nature, about $21\frac{1}{2}$ per cent of the earth's crust being formed of it. The reason its discovery was so long deferred is because, like some of the other metals, it is never found free but always combined with other elements, as, for example, with chlorine when sodium chloride (NaCl) is formed; with nitrogen and oxygen when sodium nitrate (NaNO_3), or *Chile saltpeter*, as it is called, is formed; with carbon and oxygen when sodium carbonate (Na_2CO_3), or *soda* as it is known when pure and *soda ash* when it is impure, is formed. All of these compounds are widely distributed and occur in great quantities in plants, sea water and mineral matter in general.

The History of Sodium.—The metal sodium was first produced by Sir Humphry Davy in 1807 by passing an electric current through sodium hydroxide (NaOH),¹ or *caustic soda* as it is commonly called. A year later Gay-Lussac and Thenard obtained the metal by decomposing the hydroxide with finely divided iron, and then in 1823 Brunner obtained it by reducing sodium carbonate with carbon.

Sodium obtained by any of the foregoing processes was far too costly to make it commercially available, but in 1855 Deville improved upon the method employed by Brunner so that it could be produced in large quantities and quite cheaply. This process was the only one that was used until 1886 when the Castner-

¹ This consists of 1 atom of sodium and 1 molecule of hydroxyl which, in turn, is formed of 1 atom of oxygen and 1 atom of hydrogen.

Kellner electrolytic method was devised. Practically all of the sodium that is now used is produced by it.

The Physical Properties of Sodium.—Sodium is a shining silver-white metal and a very light one, its specific gravity being only 0.98 at 0 degrees centigrade, which is the freezing point of water. At this temperature it is fairly hard and ductile but at room temperature it can be kneaded with the fingers and at 50 degrees centigrade, or 120 degrees Fahrenheit,² it has the consistency of paste; it melts at 97.5 degrees centigrade, and it boils at 742 degrees centigrade. It is one of the most electropositive of metals and one of the best conductors of heat and electricity.

The Chemical Properties of Sodium.—The ancient Romans called soda compounds *natron* and this still survives in the symbol *Na* which we use to indicate the metal sodium.³ Its atomic weight is 22.997. Sodium oxidizes readily in the air and reacts violently with water and in so doing liberates the hydrogen and produces sodium hydroxide (*NaOH*). For this reason it is kept immersed in kerosene or other light oil until such time as it is to be used.

Sodium burns with an intense yellow flame but its vapor is colorless when observed in a thin layer; but when a large amount of it is viewed by transmitted light it takes on a violet or purple color. The metal forms a large number of compounds the chief ones being sodium hydride (*NaH*), a substance that behaves very much like the metal itself; sodium chloride

² Water boils at 100 degrees centigrade or 212 degrees Fahrenheit.

³ *Na* is used because *S* is the symbol for sulphur.

(NaCl), or *common salt*; three oxides, and these are sodium oxide (Na_2O); sodium peroxide (Na_2O_2) and sodium hydroxide (NaOH), or *caustic soda*; this latter is a highly deliquescent compound, that is it attracts and absorbs moisture from the air, then gradually dissolves and finally becomes a liquid.

Other important compounds are sodium nitrate (NaNO_3) and sodium nitrite (NaNO_2); sodium carbonate (Na_2CO_3), sodium bicarbonate (NaHCO_3), or *baking soda*, sodium sulphate (Na_2SO_4) which when water is added to it forms Glauber's salts;⁴ sodium thiosulphate ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$) which is the photographer's *hypo* with which the developed plates are *fixed*; sodium tetraborate ($\text{Na}_2\text{B}_4\text{O}_7$), or *borax*; the phosphates of sodium, and some others. *Water glass*, or *soluble glass*, as it is also called, is sodium silicate (Na_2SiO_3).

The Metal Potassium.—*How It Got Its Name.*—We get the word *potash* from the old English roots *pot* and *ash* and the medieval chemists Latinized it to *potassa* and when the metal was first isolated by Davy it was given the Neo-Latin name of *potassium*.

The Occurrence of Potassium.—The metal potassium is never found free but occurs in large quantities in plants, in various minerals and in sea water. Great beds of potassium chloride (KCl) and potassium sulphate (K_2SO_4) overlay the salt deposits of Stassfurt, Germany, and these have been the chief sources of it for many years.

⁴ A salt formerly in great favor as a cathartic and so-called after J. R. Glauber, a German chemist who introduced it in the seventeenth century.

Other deposits have been found in Hanover, the Harz mountains and West Alsace and there are other and smaller deposits in Galicia and Spain. The only important potash deposit in the United States is the one at Searles Lake in California; this so-called lake is now an almost dry basin and in it there is a deposit of potassium and sodium compounds that has an average thickness of about 75 feet. The original source of potash, which is the compound that we now call potassium carbonate (K_2CO_3) is *wood ashes*, and in various localities it is still obtained from them.

The History of Potassium.—The alchemists of the Middle Ages believed that the alkalies obtained from common salt were one and the same substance and it was not until the eighteenth century that they were found to possess different properties by Duhamel in 1736. Lavoisier, the great French chemist, came to the conclusion, in 1774, that they were not simple substances but compounds.

Potassium was the first of the alkali metals to be isolated, that is obtained in a metallic form, and this was done by Davy in 1807. His process consisted of passing an electric current through a piece of moist potassium hydroxide when little beads of the metal were attracted to the negative electrode.

The Physical Properties of Potassium.—Potassium is a lustrous, bluish-white metal that is hard and brittle at the freezing point of water, *i.e.*, 0 degrees centigrade, or 32 degrees Fahrenheit. It is so soft at room temperature that it can be cut with a knife. It has a specific gravity of 0.865 and it is, therefore, so light it will float on water. (See *Figure 18.*) It

melts at 62.5 degrees centigrade, which is about 144 degrees Fahrenheit, when it becomes a liquid that looks very much like mercury. It boils at 720 degrees centigrade, or 1250 degrees Fahrenheit, when heated in hydrogen and its vapor has a green color. When heated in a Bunsen flame it and its compounds give it a violet

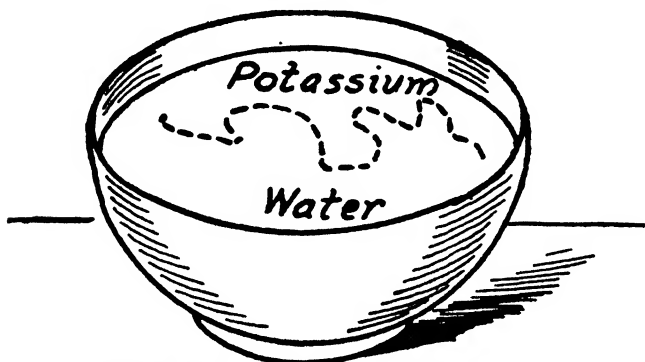


FIG. 18.—THE REACTION OF POTASSIUM WHEN THROWN ON WATER

color while its spectrum shows two lines, one of which is red and the other a deep blue.

The Chemical Properties of Potassium.—The symbol for potassium is *K* which is the abbreviation for *kalium* the Neo-Latinized name for potash.⁵ The atomic weight of potassium is 39.10 taking oxygen as equal to 16. It oxidizes very quickly in air, a freshly cut piece being covered with oxide almost instantly. When the metal is exposed to the air for a little time it is converted into potassium hydroxide (*KOH*) which is a white deliquescent solid; and continued exposure to the air results in its conversion into potassium carbonate (*K₂CO₃*), which is a white salt.

⁵ *K* is used for the symbol because *P* stands for phosphorus.

Potassium combines so rapidly with oxygen it is usually kept immersed in kerosene, or some other oil, that does not contain the gas. It also combines violently with the halogens, sulphur, phosphorus, selenium and tellurium. Chemically, the metal behaves in every essential respect like sodium—thus it combines with oxygen to form the two oxides, *i.e.*, potassium monoxide (K_2O) and potassium peroxide (K_2O_2). Potassium hydroxide (KOH), or *caustic potash*, is exceedingly soluble in water and, it follows, is highly deliquescent.

Other important compounds of the metal are: the hydride (KH), the chloride (KCl), the chlorate ($KClO_3$), the nitrate (KNO_3), the iodide (KI), the bromide (KBr), the fluoride (K_2F_2), the cyanide (KCN), which is an exceedingly poisonous salt, the sulphates (K_2SO_4) and ($KHSO_4$) and, finally, the sulphides of which there are five, namely, K_2S , K_2S_2 , K_2S_3 , K_2S_4 , and K_2S_5 .

The Metal Lithium.—*Where It Got Its Name.*—The ancient Greek word for *stone* is *lithos* and when the metal under consideration was discovered the latter name was Latinized and it became *lithium*. It was so called because it was first obtained from a mineral and this was colloquially called a stone.

The Occurrence of Lithium.—Lithium is never found free but always combined with other elements in various compounds. It occurs chiefly in the mineral amblygonite ($Li(AlF)PO_4$), which is a mixed phosphate and fluoride of aluminum and lithium, and also in lepidolite ($K_4Li(Al \cdot Fe)_3Al_4(Si_4O_{10})(SiO_4)_2$), and some other rare minerals. It is widely diffused in very small quantities.

The History of Lithium.—Its history is short. In 1817 Artvedson discovered *lithia* which is the oxide that is formed of lithium and oxygen. The metal was first isolated by Brandes, in 1822, and a quarter of a century later Bunsen and Matthieson obtained it by passing an electric current through melted lithium chloride (LiCl), a process that is still used for making it commercially.

The Physical Properties of Lithium.—Lithium is a bright, silver-white metal, the lightest of all the metals, its specific gravity being about 0.53. It not only floats on water like sodium and potassium but also on kerosene. Its melting point is 186 degrees centigrade, or 367 degrees Fahrenheit, while its boiling point is 1400 degrees centigrade, or 2550 degrees Fahrenheit; these are higher than any of the other alkali metals. It is also harder than any of the others of this group, has a ductility which is about like that of lead and can be welded at ordinary temperatures.

The Chemical Properties of Lithium.—The symbol for lithium is Li and its atomic weight is 6.94. It burns with a bright red color in the Bunsen flame and its spectrum consists of one bright red line and another and fainter orange one. When the metal is exposed to the air it quickly oxidizes and becomes covered with a yellowish-white film. It reacts with water like sodium and the other alkali metals in that it sets the hydrogen free and combines with the oxygen of it. It also reacts vigorously with hydrogen and nitrogen and forms stable compounds with all of the above gases.

Different from the hydroxide, the carbonate and the phosphate compounds of the other alkali metals which are very soluble in water, the corresponding compounds

of lithium are relatively insoluble and it is this characteristic that links it with magnesium, which is one of the alkaline earth metals. The principal lithium compounds are the oxide (Li_2O), the hydroxide ($LiOH$), the chloride ($LiCl$), the carbonate (Li_2CO_3), the citrate ($Li_3C_6H_5O_7$), the salicylate ($LiC_7H_5O_3$) and the phosphate ($Li_3PO_4 \cdot 2H_2O$).

The Metals Cæsium and Rubidium.—*How They Got Their Names.*—In the ancient Latin tongue *cæsius* means *blue* and in the Neo-Latin it becomes *cæsium*,⁶ The metal was given this name simply because its spectrum consists of two blue lines. In the same way *rubidium* in the ancient Latin language means *red* and in the Neo-Latin it becomes *rubidium*,⁷ and it was so named because its spectrum consists of two red lines.

The Occurrence of Cæsium⁸ and Rubidium.—The metals cæsium and rubidium are never found free and are nearly always together. They were first discovered in the mineral waters of Durkheim, Bavaria. They are found chiefly in very small amounts in the ashes of seaweeds, tea, tobacco and beetroot molasses. They are also found associated in the mineral lepidolite ($KLi(Al \cdot Fe)_3Al_4(Si_2O_5)(SiO_4)_3$). Cæsium is found in the form of an oxide, in the mineral pollucite ($H_2CsAl_4Si_2O_{23}$), or *pollux* as it is commonly called, which is a hydrous silicate of cæsium and aluminum and this has no rubidium mixed with it. Rubidium is obtained now from the mother-liquors of the Stassfurt, Germany, salt deposits.

⁶ Pronounced *se'-ze-um*.

⁷ Pronounced *ru-bid'-e-um*.

⁸ Also spelled *cesium*.

The History of Cæsium and Rubidium.—Both of these metals were discovered by Bunsen and Kirchhoff in 1860 with the aid of the spectroscope,* in the mineral waters of Durkheim, Germany. While the salts of cæsium had probably been examined previous to this time, they were thought to be those of potassium.

The finding of cæsium is of historic interest because it was the first metal to be discovered with the aid of the spectroscope. In the following year (1861) Bunsen obtained the chlorides of these metals by evaporating a large amount of the Durkheim mineral water and then by separating them and passing an electric current through them he was able to separate their respective metals from them which came to the surface in the form of globules.

The Physical Properties of Cæsium and Rubidium.—Both cæsium and rubidium are silvery-white metals and both are very light, the former having a specific gravity of 1.88 and the latter of 1.52. Both are soft metals, but rubidium is especially so for even when it is at a temperature of 10 degrees centigrade, it is as pliable as wax. Cæsium melts at 26 degrees centigrade, or 80 degrees Fahrenheit, and rubidium at 38.50 degrees centigrade, or 101.3 degrees Fahrenheit, and gives off a bluish vapor at a dull red heat. Cæsium is the most electropositive element known and rubidium follows it a close second.

The Chemical Properties of Cæsium and Rubidium.—The symbol for cæsium is *Cs* and its atomic weight is 132.81, while the symbol of rubidium is *Rb* and its atomic weight is 85.44. The salts of cæsium and

* It was Bunsen and Kirchhoff who invented the spectroscope.

rubidium act chemically very much like those of potassium in that they oxidize rapidly in air, decompose water, liberate the hydrogen of it and ignite it. The chief compounds that they form are the caesium oxides CsO and Cs_2O ; the rubidium oxides, RbO and Rb_2O ; the hydroxides, $CsOH$ and $RbOH$; the chlorides, $CsCl$ and $RmCl$; the bromides, $CsBr$ and $RmBr$; the iodides, CsI and RbI , etc.

The salts of potassium, caesium and rubidium when combined with platinum give three insoluble compounds and these are potassium chloroplatinate (K_2PtCl_6), caesium chloroplatinate (Cs_2PtCl_6) and rubidium chloroplatinate (Rb_2PtCl_6). Since the solubilities of all these platينات are different they can be separated from each other by washing them with cold water and the metal of each one can then be isolated.

CHAPTER V

THE ALKALINE EARTH METALS

AFTER the important discoveries of the alkali group of metals had been made, chemists found another group that acted like those of the foregoing one in that the metals of it would displace hydrogen from cold water and in so doing they produced the corresponding hydroxides. As the compounds of this latter group would not dissolve easily like those of the alkali metals they were called *alkaline earths* and these included the metals calcium, magnesium, strontium, barium and radium. Although radium belongs chemically to the alkaline earth group of metals I shall describe it in a later chapter along with the other radioactive metals.

The Metal Calcium.—*How It Got Its Name.*—The ancient Romans called *lime*, which is calcium oxide, *calx*; from this was derived the word *calcis* and when the metal was discovered it was given the Neo-Latin name of *calcium*.

The Occurrence of Calcium.—Like the metals of the alkali group calcium is never found free but it occurs very plentifully and is widely distributed in combination with other elements in various common minerals. Chief among these are *calcite*, which is calcium carbonate (CaCO_3) and this includes chalk, marble and limestone; *gypsum*, which is hydrated calcium sulphate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and *apatite*, which is calcium phosphate-fluoride ($3\text{Ca}_3(\text{PO}_4)_2 \cdot \text{CaF}_2$). Calcium is also

found in fresh waters, in plants, and it forms a large part of the bones and shells of animals. The spectro-scope shows that there is calcium in the sun.

The History of Calcium.—The metal calcium was first isolated by Davy in 1808 and this he did by passing an electric current through melted calcium chloride (CaCl_2). In the same year Berzelius and Pontin independently obtained it from its compounds.

The Physical Properties of Calcium.—Calcium is a bright, silver-white crystalline metal with a yellowish tinge. It is just about as hard as lead and can be cut, drawn into wire or rolled into sheets. Its specific gravity is 1.58 and it melts at a temperature of 810 degrees centigrade, or 1490 degrees Fahrenheit. There are only four other metals that are better conductors of electricity than calcium.

The Chemical Properties of Calcium.—The symbol for calcium is Ca and its atomic weight is 40.0. It is not attacked by dry air at ordinary temperatures but in moist air it rapidly becomes coated with the hydroxide ($\text{Ca}(\text{OH})_2$). When it is highly heated in air it burns with a reddish flame and forms calcium oxide (CaO) and calcium nitride (Ca_3N_2). (See Figure 19).

Like the alkali metals it rapidly decomposes water, liberating the hydrogen of the latter and forming its hydroxide ($\text{Ca}(\text{OH})_2$). The metal combines with nearly every acid and produces numerous compounds, the chief ones, other than those named above, being the hydride (CaH_2), or *hydrolyte* as it is commonly known; the chloride (CaCl_2), and the fluoride (CaF_2), which occurs in nature as *fluorite* or *fluor spar*.

Other compounds of calcium are the carbonate

(CaCO_3), of which eggshells, oyster shells, coral and pearls are formed; the oxide (CaO) which is *quicklime*; the oxalate (CaC_2O_4); the carbide (CaC_2), which produces *acetylene gas* when it is made to react with water; bleaching powder ($\text{Ca}(\text{OCl})\text{Cl}$); the nitrate

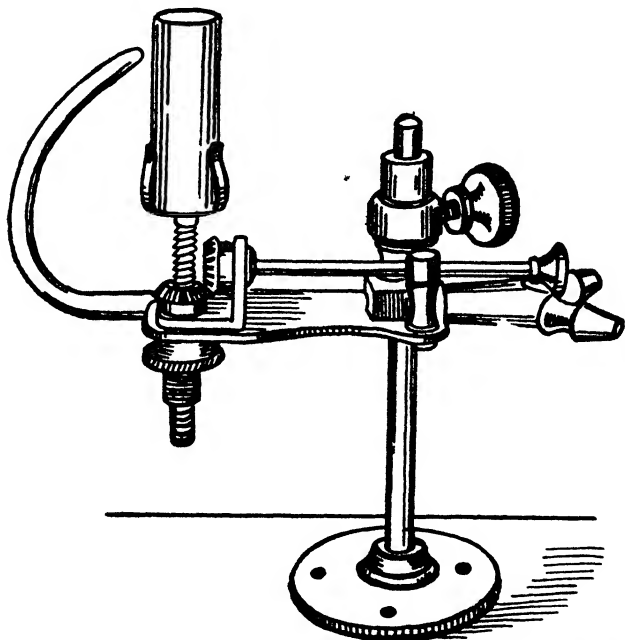


FIG. 19.—THE CALCIUM LIGHT, ALSO CALLED THE OXY-HYDROGEN LIGHT, AND THE LIME-LIGHT

($\text{Ca}(\text{NO}_3)_2$); the sulphate (CaSO_4) which in granular masses is called *alabaster* and in crystallized form *gypsum*, and *selenite*; and the sulphide (CaS) a compound which after it is exposed to the light will shine in the dark.

The phosphates, of which phosphorite ($\text{Ca}_3(\text{PO}_4)_2$),

apatite ($3\text{Ca}_3(\text{PO}_4)_2, \text{CaF}_2$), a common mineral, and the orthophosphate, or *superphosphate* ($\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{CaSO}_4$), as it is commonly known, form the chief compounds; the cyanamide (CaCN_2), or *nitro-lime* as it is called, which is formed by heating calcium carbide when it absorbs nitrogen, and finally, calcium silicate (CaSiO_3) which with sodium silicate (Na_2SiO_3) form the chief constituents of glass.

The Metal Magnesium.—*How It Got Its Name.*—Magnesium gets its name from the town Magnesia, in Thessaly, Asia Minor, and this is the way it came about. There is a mineral found in Magnesia that is called *magnesite*¹ from which the metal was first obtained.

The Occurrence of Magnesium.—Magnesium is never found in its free metallic state but it occurs plentifully in its compounds which are widely distributed in the earth's crust. The chief sources of the metal are the minerals *magnesite*, which is magnesium carbonate (MgCO_3), and *dolomite*, a double salt formed of calcium carbonate and magnesium carbonate ($\text{MgCO}_3, \text{CaCO}_3$); its hydrates as magnesium chloride ($\text{MgCl}_2, 6\text{H}_2\text{O}$) and magnesium sulphate ($\text{MgSO}_4, \text{H}_2\text{O}$), which comes from the Stassfurt deposits; in the *silicates* as *olivine*, which is magnesium orthosilicate (Mg_2SiO_4); in *serpentine*, a hydrated disilicate ($(\text{Mg}, \text{Fe})_3\text{Si}_2\text{O}_7, 2\text{H}_2\text{O}$); in *asbestos*, an anhydrous silicate ($(\text{Mg}, \text{Ca})(\text{SiO}_3)_4$); *talc* or *soapstone*, as it is also called, an acid magnesium silicate

¹ Do not confuse this mineral with *magnetite*, a mineral that contains iron and which is magnetic. It is from the root *Magnesia* that *magnet* and all other like words have been derived.

($H_2Mg_2(SiO_3)_4$); in *carnallite*, a hydrous chloride of potassium and magnesium ($KMgCl_3 \cdot 6H_2O$), etc.

The History of Magnesium.—The metal magnesium was first isolated by Davy in 1808 and this he did by two different processes, namely, (1) by passing an electric current through melted magnesium chloride, and (2) by the reduction of incandescent magnesium oxide in an atmosphere of potassium vapor. Bussy, in 1830, obtained a larger and purer amount of the

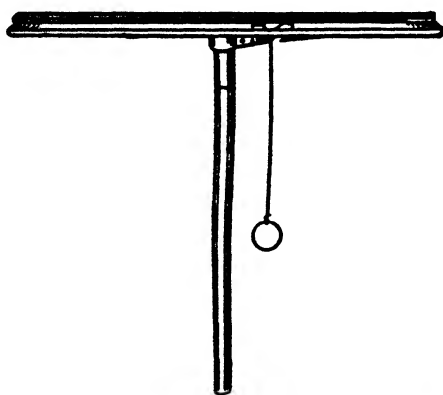


FIG. 20.—THE MAGNESIUM FLASHLIGHT, USED FOR MAKING FLASHLIGHT PHOTOGRAPHS

metal by heating a mixture of potassium and anhydrous magnesium chloride to redness.

The Physical Properties of Magnesium.—When magnesium is pure it has a lustrous silvery-white color and is very light, having a specific gravity of 1.74. It is a fairly hard metal, brittle when cold but when it is heated it can be rolled into wire or ribbon and is malleable. Its melting point is 651 degrees centigrade, or 1204 degrees Fahrenheit, and its boiling point is 1100

degrees centigrade, or 2012 degrees Fahrenheit. (See *Figure 20*.)

The Chemical Properties of Magnesium.—The symbol of magnesium is *Mg* and its atomic weight is 24.32. The chemical behavior of magnesium bears so strong a resemblance to calcium that the two metals were in time past often confused with each other. Since their chemical properties are so much alike I have given magnesium a place here in this chapter with the alkaline earth metals; however, according to the *periodic system*,² it belongs to the fourth group of the metallic elements which named are beryllium, zinc, cadmium and mercury.

Magnesium does not oxidize in dry air but it does so in moist air to a slight extent. When heated to a cherry-red in a closed retort it passes over in a vapor and when this cools it takes on the form of lustrous white crystals. When the metal is burned in air it gives a dazzling white light (see *Figure 20*) and at the same time combines with the nitrogen of it when the solid nitride (Mg_3N_2) is formed; and also with the oxygen when the oxide (MgO) is formed.

One of the chief compounds of the metal is its oxide (MgO), or *magnesia* as it is called; this is a white substance that reacts with acids as a base and, it follows, forms various magnesium salts. Magnesia will not dissolve in water but hardens into a solid mass when

² The *periodic system* is a classification of the chemical elements made by the Russian chemist Mendelejeff about 1870. You will find a simple description of it in my book *How to Understand Chemistry*, published by D. Appleton and Company, New York.

exposed to air, and is one of the most infusible substances known. The oxyhydrogen blowpipe has no effect upon it, other than to make it glow with a dazzling light, but it can be melted in the electric furnace.

Other compounds of the metal are its chloride ($MgCl_2, 6H_2O$); the carbonates, namely, normal carbonate ($MgCO_3$), which in its natural state is the mineral magnesite, and magnesia alba ($Mg(OH)_2, 4MgCO_3, 5H_2O$); the sulphate ($MgSO_4$) of which the heptahydrate³ ($MgSO_4, 7H_2O$), commonly called *Epsom salts*, is a form; the sulphide (MgS) which is made by heating the metal with sulphur, and, finally, the *phosphates of magnesia*, of which there are a couple of forms.

The Metal Strontium.—How It Got Its Name.—There is a village in Argyllshire, Scotland, called Strontian, and a certain mineral which has been found near by was given the name *strontianite*. It is formed of strontium carbonate ($SrCO_3$) and when the metal was isolated from it it was called *strontium*.⁴

The Occurrence of Strontium.—The metal strontium not only occurs in strontianite but it is more plentiful in *celestite*, a native strontium sulphate ($SrSO_4$); in *brewsterite*, which is essentially $H_4(Sr, Ba, Ca)Al_2Si_6O_{18} + H_2O$, a mineral containing strontium together with barium and calcium, and also in small amounts in aragonite, calcite and dolomite. It is also found in minute quantities in sea water, in soils, and the ashes of some plants.

³ Meaning that it has 7 molecules of water.

⁴ Pronounced *stron'-she-um*.

The History of Strontium.—The earth,⁵ as the oxide of strontium was formerly called, was recognized by Cruikshank in 1787 and by Hope in 1792. Klaproth found, in 1793, that it gave a carmine red color when burned in a flame. The metal was first isolated, in an impure state, however, by Davy and this he did by passing an electric current through moistened strontium hydroxide of the chloride. The metal has since been obtained in its pure state by Guntz and Roederer by heating strontium hydride in a vacuum to 1000 degrees centigrade, or 1832 degrees Fahrenheit.

The Physical Properties of Strontium.—Strontium is a silver-white metal when pure but yellow when it is impure. It has a specific gravity of about 2.5 and is a little harder than calcium. It melts at red heat, which is about 800 degrees centigrade, or 1472 degrees Fahrenheit, and when more highly heated it burns with a brilliant red color. It is both malleable and ductile.

The Chemical Properties of Strontium.—The symbol for strontium is *Sr* and its atomic weight is 87.63. The compounds of the metal behave in all respects quite like those of calcium. It oxidizes rapidly when exposed to the air and not only burns in it but also in oxygen, chlorine, bromine and the vapor of sulphur. Strontium is less electropositive than calcium and the alkali metals.

The chief compounds of strontium are the *oxides*, namely, the monoxide (SrO) and the dioxide (SrO_2);

⁵ It was once believed that the earths were elements and not compounds.

the hydroxide ($Sr(OH)_2$); the chloride ($SrCl_2 \cdot 6H_2O$); the sulphate ($SrSO_4$) and the nitrate ($Sr(NO_3)_2$).

The Metal Barium.—*How It Got Its Name.*—This metal got its name from *barote* which is the Greek word for *heavy* and it was called *barium* by Berzelius and Pontin in 1808.

The Occurrence of Barium.—This metal never occurs in its free state but always in combination with other elements. It is present in some mineral waters and in nearly all of the primary rocks. Its chief sources are the minerals *witherite*, which is native barium carbonate ($BaCO_3$) and *barite*, or *heavy-spar* as it is commonly known, which is barium sulphate ($BaSO_4$).

The History of Barium.—The mineral *barite* was the first compound that contained barium which was known. Marggraf showed in 1750 that barite had sulphur in it and then Scheele and Gahn found that it contained another substance which had not been known before. To this Bergman gave the name of *terra ponderosa*, which in Latin means *heavy earth*. In 1779 de Morveau called the earth *barote*, which is the Greek word for *heavy* and, finally, Lavoisier changed it to *baryta*⁶ which is the common name of barium oxide (BaO) and it is still in use at the present time. The metal was isolated by Berzelius and Pontin in 1808 when it was given the Neo-Latin name of *barium*.

The Physical Properties of Barium.—When barium is pure it has a silver-white color. Its specific gravity is 3.78, it melts at 850 degrees centigrade, or 1580

⁶ Pronounced *ba-ri'-ta*.

degrees Fahrenheit, and vaporizes at 950 degrees centigrade, or 1742 degrees Fahrenheit. When in a powdered state barium will catch on fire spontaneously and it burns with a green color.

The Chemical Properties of Barium.—Most of the compounds of barium are more soluble in water than those of the other alkaline earths and all of them that can be so dissolved are poisonous. The chief compounds of this metal are the carbonate ($BaCO_3$); the chlorate ($Ba(ClO_3)_2$) and the chloride ($BaCl_2$); the oxide (BaO) and the peroxide (BaO_2); the hydroxide ($Ba(OH)_2$) which is the most soluble of the hydroxides of the alkaline earth group, and a solution of which is called *baryta-water*; the hydrate ($Ba(OH)_2 \cdot 8H_2O$), a compound which crystallizes when a saturated solution is in the process of cooling off; the nitrate ($Ba(NO_3)_2$); the sulphate ($BaSO_4$), which is one of the most insoluble salts that is known; the sulphide (BaS) a highly phosphorescent salt and which goes by the name of *Bologna phosphorus*. After it has been exposed to the light of the sun or any other actinic source of light, it will shine in the dark for hours with a bright yellow light.

CHAPTER VI

THE UNCOMMON METALS

I HAVE classed those metals as uncommon whose names are unfamiliar to the average person, that are more or less rare in nature, or that are of small commercial importance. Very few of the uncommon metals are used in their pure metallic state but many of them are of great value in forming alloys with other metals or compounds with other elements. The uncommon metals far outnumber the common ones and so I have put the outstanding ones down in this chapter in alphabetic order to the end that you can quickly put your finger on the one you want.

The Metal Arsenic.—*How It Got Its Name.*—Arsenic gets its name from the Greek *arsenikon* and the Latin *arsenicum* and these come from *arsen* which means *male* or *masculine*, so-called on account of its strength.

Occurrence of the Metal.—Arsenic is found in its free metallic form and also in ores along with iron, lead, cobalt, nickel and antimony. It is found in various minerals combined with sulphur as arsenic¹ monosulphide (AsS), or *realgar* as it is commonly called, and trisulphide (As_2S_3), which is known as *orpiment*. Arsenic is widely distributed in nature but the total amount of it is comparatively small. It is found in

¹ Pronounced *ar'-se-nik* when used as an element and *ar-sen'-ic* when in combination with other elements.

Siberia, various countries of Europe, Japan, British Columbia and the United States.

History of the Metal.—The compounds of arsenic have been known from antiquity, the yellow arsenic trisulphide (As_2S_3), or *orpiment*, having been described by Theophrastus, who called it *arseinikon*, a Greek word meaning the *masculine one*, as it was used to paint the sun-burned faces of the men.

The Physical Properties of Arsenic.—It is steel-gray in color and crystalline in form; it has a specific gravity of 5.7 and is very brittle. When freshly broken it shows a high luster but oxidizes when exposed to air. The metal vaporizes at 180 degrees centigrade, or 356 degrees Fahrenheit, and when the vapor is suddenly cooled a yellow and less stable form results which will dissolve in carbon disulphide; it is phosphorescent in the air and in other ways acts very much like white phosphorus.

The Chemical Properties of Arsenic.—The symbol of arsenic is *As* and its atomic weight is 74.96. This metal combines directly with oxygen, sulphur, the halogens, and many of the metals. When burned in air it forms clouds of arsenic trioxide (As_2O_3) which is a solid white substance. When boiled with nitric acid, or other powerful oxidizing agent, it produces arsenic acid (H_3AsO_4). When combined with hydrogen it forms arsine (AsH_3) and when melted with zinc it gives zinc arsenide (Zn_3As_2). Arsenic and all of its compounds are extremely poisonous but, paradoxically, there are small amounts of it in the human body.

The Metal Beryllium.—*Its Name.*—This metal got its name from the Greek *berillion* which is the diminutive of *beryl* and this means the mineral *beryl*; it is so-called because it was first found in *beryl*. It is also called *glucinum* (*Gl*) from the Greek word *glykys* which means *sweet* because it has a sweet taste.

Its Occurrence.—Beryllium is never found in its free metallic state but occurs with other elements in various minerals, such as *beryl*, which is a metasilicate of beryllium and aluminum ($Be_3Al_2(SiO_3)_6$), *chrysoberyl*, a beryllium aluminate ($BeAl_2O_4$) and *phenacite*, a silicate of beryllium (Be_2SiO_4).

Its History.—The oxide of beryllium (BeO) was first recognized by Vauquelin in 1798, but the metal was not isolated until 1828 when Wöhler obtained it by fusing beryllium chloride ($BeCl_2$).

Its Physical Properties.—Beryllium is a hard, steel-white, malleable metal, has a specific gravity of 1.93 and a melting point of 1400 degrees centigrade, or 2550 degrees Fahrenheit.

Its Chemical Properties.—The symbol of beryllium is *Be* and its atomic weight is .91. When it is powdered it burns in the air and displaces hydrogen from dilute acids and, when heated, from caustic potash. When the metasilicate of beryllium and aluminum ($Be_3Al_2(SiO_3)_6$), which is *beryl*, is colored with a little chrominum silicate it becomes an emerald.

The Metal Cadmium.—*Its Name.*—The name *kalamine* was used for an ancient Greek alloy made of lead, tin, antimony and zinc; from this came the Latin *cadmia* which means the dross or slag that resulted when the ore of zinc was reduced. The metal *cadmium*

was so named because the crust in zinc furnaces contained from 10 to 20 per cent of it.

Its Occurrence.—Cadmium is never found native but occurs in the rare mineral known as *greenockite*² which is formed of cadmium sulphide (CdS), and in this there is only a very small amount, usually about 0.5 per cent. It is also found in zinc ores. The chief sources of the metal are Bohemia, Hungary, and Lehigh, Pennsylvania, though the latter place produces only very small amounts of it.

Its History.—The metal was isolated by Stromeyer, in 1817, who obtained it from zinc carbonate ($ZnCO_3$) ore.

Its Physical Properties.—Cadmium is a white, lustrous metal that has a bluish tinge like that of tin, which it somewhat resembles in its physical aspects; thus it makes the same peculiar crackling noise, or *cry* as it is called, that tin does when it is being bent. It is a malleable, ductile metal and will take a high polish. It has a specific gravity of 8.6 and a melting point of 320 degrees centigrade, or 608 degrees Fahrenheit. It boils at 778 degrees centigrade, or 1432 degrees Fahrenheit, and then yields a yellow vapor.

Its Chemical Properties.—The symbol for cadmium is Cd and its atomic weight is 112.4. Chemically, it acts in some respects like zinc. Cadmium forms only one oxide (CdO) which is a brown powder and this can be obtained by burning the metal in air. It forms the chloride ($CdCl_2$), the iodide (CdI_2), the basic hydroxide ($Cd(OH)_2$), the carbonate ($CdCO_3$), the sulphate ($CdSO_4$), and the sulphide (CdS).

² This mineral is also known as *cadmium blende*.

The Metal Columbium.—*Its Name.*—The poetical name of *Columbia* was given to America in honor of Columbus who discovered it and the metal was named after it. The metal is also called *niobium* which is the Neo-Latinized form of *Niobe*, a Greek goddess who wept much and was finally turned into stone where she still continued her weeping.

Its Occurrence.—Columbium is never found free and only in small amounts in a few minerals, the chief ones of which are *columbite*, which is a columbate of iron ($Fe(CbO_3)_2$), and *tantalite*, a tantalate of iron ($Fe(TaO_3)_2$). These minerals are found in Sweden, Mexico, in Central and South American countries and in various parts of the United States.

Its History.—The metal was discovered by Hanchett in 1810, and it was he who gave it the name of *columbium*. It was rediscovered by Ross in 1846 and he renamed it *niobium*. This he did because it resembled tantalum, a metal that had previously been found and named after the Greek god Tantalus, who was the father of Niobe. Columbium was first isolated by Bloomstead in 1866 who reduced its chloride with hydrogen.

Its Physical Properties.—Columbium is a bright lustrous metal of a steel-gray color and has a specific gravity of 12.7. It is about as hard as wrought iron, is sufficiently malleable so that it can be welded and has a melting point of 1950 degrees centigrade, or 3542 degrees Fahrenheit.

Its Chemical Properties.—The symbol for columbium is *Cb*, or if you prefer to call it *niobium* then *Nb*, and its atomic weight is 93.1. It burns when

heated in the air, has feeble base-forming properties and its chief compounds are the salts called *columbates* or *niobates*. It forms four oxides and these are the dioxide (Cb_2O_3); the trioxide (Cb_2O_5); the tetroxide (Cb_2O_4) and the pentoxide (Cb_2O_5). It forms two chlorides, namely the pentachloride ($CbCl_5$) and the oxychloride ($CbOCl_2$). It also forms the pentafluoride (CbF_5), and a percolumbic acid ($HCbO_4, H_2O$) has been made.

The Metal Germanium.—*Its Name.*—The ancient Romans called that great territory which lies north of the Alps and east of the Rhine *Germania* and in later times a more restricted part of it was named *Germany*. Winkler, who discovered the new metal, was a German and so he gave it the Neo-Latin appellation of *germanium* in honor of his native land.

Its Occurrence.—Germanium is a very rare metal. It is obtained from germanium dioxide (GeO_2) which is found in the concentrate from certain residues that result when zinc ores are smelted. It is also found in *argyrodite*, which is a silver sulpho-germanate (Ag_8GeS_8), a mineral that occurs in small amounts in Saxony and in larger amounts in Bolivia.

Its History.—The discovery of germanium was predicted by Mendeleeff³ in 1871. He indicated its properties by means of his *periodic system*.⁴ He gave the metal the provisional name of *ekasilicon*, the prefix *eka* being the Sanskrit word which means *next in order*.

³ The *Standard Dictionary* spells it *Mendelyeev*, but chemists spell it *Mendeleeff*.

⁴ For an explanation of the periodic system see my *How to Understand Chemistry*, published by D. Appleton and Company, New York.

Winkler discovered it in the mineral argyrodite in 1886.

Its Physical Properties.—Germanium has a gray-white color and a fine luster. Its specific gravity is 5.35 and it melts at 958 degrees centigrade, or 1756 degrees Fahrenheit. It is a very brittle metal and cannot be drilled.

Its Chemical Properties.—The symbol for germanium is *Ge* and its atomic weight is 72.6. It is a transition element being about halfway between carbon and tin. When heated in oxygen to 730 degrees centigrade, or 1346 degrees Fahrenheit, it is partly oxidized and changed to the dioxide (GeO_2), which is a dense white powder. It forms two oxides and these are germanous oxide (GeO) and germanic oxide (GeO_2). Like carbon the metal forms an unstable compound with hydrogen, and with hydrogen and chlorine it gives germanium chloroform ($GeHCl_3$). Like carbon, silicon and tin it gives a volatile chloride ($GeCl_4$), and, finally, like tin and gold it produces complex sulphides such as potasso-germanium sulphide (K_2GeS_3).

The Metal Manganese.—*Its Name.*—The name *manganese* ⁵ comes from the same root as magnesium, i.e., *magnesia*. As a matter of fact the metal was at first called *magnesium* because it was obtained from a compound called *magnesia nigra*, which we now call manganese dioxide (MnO_2). As the same name for two different metals resulted in considerable confusion Buttmann, in 1808, arbitrarily changed it to manganese and it has been so-called ever since.

⁵ Pronounced *man'-ga-nese*.

Its Occurrence.—Manganese is never found free but occasionally as an alloy with iron in meteorites. The chief source of the metal is the mineral *pyrolusite*, which is the dioxide of manganese (MnO_2) and this always has some iron in it. Many other minerals contain it as *braunite*, a silicate of manganese ($3Mn_2O_3, MnSiO_3$), manganite, the hydrous oxide of manganese ($MnO(OH)$), both of which are widely distributed, and it is also found in other metal-bearing ores. Before the World War the largest amounts of manganese ores came from Russia, and the next greatest producers were India and Brazil. Manganese ores found in the United States are not as high grade as those of Russia.

Its History.—The mineral pyrolusite, which is manganese dioxide (MnO_2) has been known from antiquity, and Basil Valentine, the alchemist, as well as chemists who came after him, believed it to be an iron ore. Pott showed in 1740 that it could be made to produce a definite series of salts and Sheele proved that it was the oxide of a new but unknown metal. Manganese was first isolated by Gahn in 1774. Gahn obtained it from manganous carbonate ($MnCO_3$), Brunner obtained it from manganous fluoride (MnF_2) and, finally, Moissan obtained it from manganese chloride ($MnCl_2, 4H_2O$) in the electric furnace.

Its Physical Properties.—Manganese is a grayish-white, lustrous metal with a reddish tinge. Its specific gravity is 8.0. It is about as hard and brittle as iron and resembles this latter metal in many of its physical and chemical properties, but it is not magnetic. It has a melting point of 1207 degrees centigrade, or 2200

degrees Fahrenheit, and is not malleable. (See Figure 21.)

Its Chemical Properties.—The symbol for manganese is *Mn* and its atomic weight is 54.93. When it is pure it is not affected by dry air but moist air oxidizes it a little. Manganese has five valences and, it follows, it forms a series of five compounds which are entirely different from each other. They are (1) the *man-*

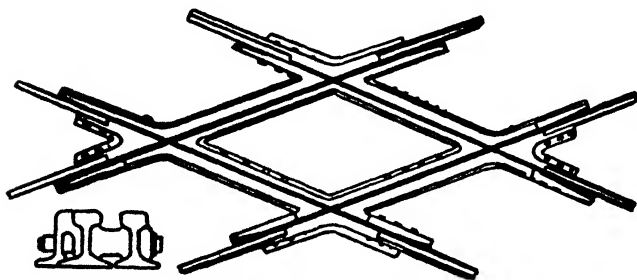


FIG. 21.—SOLID MANGANESE RAILROAD CROSSING
(Courtesy of American Manganese Steel Co.)

ganous compounds, MnO , $Mn(OH)_2$, $MnSO_4$, etc.; (2) the *manganic compounds*, which are Mn_2O_3 , $Mn(OH)_3$, $Mn_2(SO_4)_3$ and $MnCl_3$; the *manganites*, which are MnO_2 , H_2MnO_3 and $CaMnO_3$; the *manganates*, which are MnO_3 , H_2MnO_4 and K_2MnO_4 ; and, the *permanganates*, which are Mn_2O_7 , $HMnO_4$, and $KMnO_4$.

The Metal Molybdenum.—*Its Name.*—The name *molybdenum* comes from the ancient Latin word *molybdana* which in ancient Roman times meant the mineral *galena*, a lead sulphide (PbS), or *litharge*, a lead oxide (PbO). Thus Pliny in his writings used the word *molybdana* to mean any substance which

contained lead. As late as the middle of the eighteenth century this word was used to mean galena but about that time it was changed over to mean (a) *graphite* or *plumbago* or *black lead*, as it is variously called, but which is not lead at all but carbon, and (b) the mineral *molybdenite* which is molybdenum disulphide (MoS_2). It was Sheele who first pointed out the difference between these two substances in 1778, as well as to convert molybdenum disulphide into *molybdic acid*.⁶ It was not until nearly the end of the eighteenth century when the metal was isolated by Hjelin that it was given the Neo-Latin name of *molybdenum*.

Its Occurrence.—Molybdenum is never found free in nature but is always combined with other substances. There are numerous minerals which contain it but only two of them are of commercial importance and these are *molybdenite* which is molybdenum disulphide (MoS_2), and *wulfenite*, which is lead molybdate ($PbMoO_4$). These ores are found in the United States, Canada and other parts of the world.

Its Physical Properties.—Molybdenum is a silver-white metal and has a specific gravity of 9.01. It is about as hard as iron and like the latter takes up carbon and can be tempered. Its melting point is higher than platinum being 2535 degrees centigrade, or 4595 degrees Fahrenheit. It is malleable and can be welded; it is ductile and can therefore be drawn into wire.

Its Chemical Properties.—The symbol of molybdenum is *Mo* and its atomic weight is 96.0. It behaves chemically in some respects like a nonmetal as, for ex-

⁶ There are several of these acids the simplest of which is H_2MoO_4 .

ample, it does not easily replace the hydrogen in acids when dissolved in them to form salts, although its oxides will dissolve in acids.

The metal forms several oxides the chief ones of which are MoO_2 , Mo_2O_3 and MoO_3 ; when this last named substance, which is the trioxide, is made to combine with water it forms compounds that are called *molybdic acids*, of which the simplest is H_2MoO_4 and this consists of needlelike crystals, and $H_2MoO_4, 4H_2O$ which is also crystalline. When these acids are made to combine with the bases of other metals they form a series of compounds that are known as the *molybdates*.

The Metal Selenium.—*How It Got Its Name.*—Selenium is the Neo-Latin name for *selene* which is the ancient Greek appellation for the *moon*. The metal was given this name because it closely resembles tellurium which had been discovered a short time before it and which was named from the Latin word *tellus* meaning the *earth*.

Its Occurrence.—Once in a long while selenium is found in its free state in native sulphur and more frequently in the mineral *iron pyrite* which is a ferrous disulphide (FeS_2), or *fool's gold* as it is commonly called. It is also found in the dust-flues of the pyrite burners in sulphuric acid works. The chief source of selenium is the *selenides*, as the minerals are called, in which it is combined with some of the heavy metals. The principal ones of these are *clansthalite*, a lead selenide ($PbSe$); *eucairite*, a copper and silver selenide ($(Ag,Cu)_2Se$); *crookesite*, a copper, thallium and silver selenide ($(CuAgTl)_2Se$), etc.

Its History.—Selenium was discovered by Berzelius in 1817. (See *Figure 22*.) He isolated it from the crystals formed in lead chambers of sulphuric acid works. In 1909 Warren found traces of it in iron meteorites.

Its Physical Properties.—Selenium is a *yes* and *no* element by which I mean that sometimes it is a metal



FIG. 22.—A PORTRAIT OF BERZELIUS, THE DISCOVERER OF SELENIUM

From a cast made of selenium.

and sometimes it is a nonmetal. As a matter of fact, it is *allotropic*, that is it takes on different forms just as graphite may take on the form of the diamond and the other way about, and each form has a different set of properties.

The three chief forms of selenium are (1) the red, amorphous form, (2) the brownish-black vitreous form, and (3) the gray crystalline form, and this is the metallic form of it. This last named form is practically a nonconductor of electricity in the dark but is a very good conductor in the light.⁷ The metallic form of selenium has a specific gravity of 4.8.

⁷ When selenium is exposed to the light its electrical conductivity is proportional to the light that falls on it.

Its Chemical Properties.—The symbol for selenium is *Se* and its atomic weight is 79.2. It burns in air with a purple flame and gives off a disagreeable odor very much like that of horse-radish. The element combines directly with numerous metals, burns in oxygen when they form selenium dioxide (SeO_2) and combines violently with chlorine. The chief compounds of selenium are the dioxide (SeO_2), the trioxide is unknown; selenic acid (H_2SeO_4) which is a white solid substance; selenium oxychloride ($SeOCl_2$) which is a powerful corrosive and a violently active liquid, and the tetrachloride ($SeCl_4$).

The Metal Titanium.—*Its Name.*—One of the legends of Greek mythology tells about the offspring of Uranus and Gæa, who were known as the *Titans* and all of whom were giants of strength. For this reason the word Titan has come down to us as the incarnation of the power to resist force. The metal *titanium* was named after it because of the strength of the chemical combination in which it is held by its natural compounds and which made its isolation a difficult task.

Its Occurrence.—Titanium is never found free in nature but it occurs as a black mineral called *menachanite*⁸ in the sands of Menaccan in Cornwall, England, and more plentifully in the minerals *anatase*, or *octohedrite* as it is also called, *brookite*, and *rutile*, all of which consist of titanium dioxide (TiO_2); in *ilmenite*, which is ferrous titanate ($FeTiO_3$) that is, a compound of iron, titanium and oxygen; *titanate*, which is calcium silicotitanate ($CaTiSiO_5$), and in smaller amounts in some other minerals. While the deposits of the

⁸ Pronounced *me-nach'-a-nite*.

various titanium minerals are widespread those of importance are few and far between, the chief ones being in the United States, Canada, Norway, South Australia, Quebec, Canada, and Sweden.

Its History.—A new metal was discovered by Gregor in 1789 in the mineral menachanite and he named it *menachite*. In 1793 Klaproth found a new metal in ilmenite and he called it *titanium* because he could not isolate it, and later he ascertained that the minerals menachanite and ilmenite were one and the same and, it follows, the metals they contained were identical; for this reason the new metal was thenceforth known as titanium.

Lampadius, in 1797, tried to isolate the metal and later on Berzelius made the attempt, but they only succeeded in getting either the nitride or carbide of it. In 1895 Moissan obtained the metal free from nitrogen and oxygen but it had about 2 per cent of carbon in it. Finally, Hunter isolated it in a practically pure state.

Its Physical Properties.—Titanium is a silver-white metal and when fractured it looks very much like steel. Its specific gravity is 4.5 and it melts at about 1850 degrees centigrade, or 3362 degrees Fahrenheit. When cold it is hard and brittle but when heated to redness it is as malleable as iron.

Its Chemical Properties.—The symbol for titanium is *Ti* and its atomic weight is 47.9. When the metal burns in air it gives a dazzling white light. It has a great affinity for oxygen, nitrogen and carbon. When combined with oxygen it forms three oxides and these are TiO_2 , TiO , and Ti_2O_3 . When the dioxide (TiO_2)

is made to combine with bases the *titanates*, as the salts of titanitic acid (H_2TiO_3) are called, are formed.

The Metal Tellurium.—Its Name.—In the ancient Roman religion *Tellus*, or *Tellus Mater*, which means *Mother Earth*, was the goddess who personified the earth. Her duty was to receive and nourish the seed sown and to care for the growing fields. The metal under consideration was named *tellurium* by Klaproth after *tellus* which in Latin means *the earth*.

Its Occurrence.—Tellurium is occasionally found in small amounts in its free state as a crystalline substance but its chief source is in minerals that contain other metals. Among these are *tellurite*, which is tellurium oxide (TeO_2); *sylvanite* which is a silver-gold telluride* ($AgAuTe_2$); *tetradymite*, which is bismuth telluride ($Bi_2(Te,S)_3$), and in various other minerals. Tellurium and its minerals are widely distributed, being found in Ontario, Mexico, South America, Western Australia, Japan, Colorado and California. The chief source of the metal is, however, that obtained from the flue dust of sulphuric acid works along with selenium.

Its History.—In 1782 von Richenstein discovered a new metal in a gold ore, and in 1798 it was isolated by Klaproth who, as I have said above, named it *tellurium*.

Its Physical Properties.—Tellurium is a white, shining crystalline metal and has a specific gravity of 6.27. It melts at 452 degrees centigrade, or 846 degrees Fahrenheit, and boils at 1400 degrees centigrade, or 2552 degrees Fahrenheit. It is a curious allotropic ele-

* The word *telluride* means any compound that is formed of *tellurium* and another element or radical that acts as an element.

ment having any one of three different states or conditions, very much like selenium, and on this account it was given the Latin appellations of *aurum paradoxum* and *metallum problematum*. When in the metallic state its electrical conductivity varies according to the amount of light that falls on it though this is not nearly as great as in the case of selenium.

Its Chemical Properties.—The symbol of tellurium is *Te* and its atomic weight is 127.5. It does not oxidize in air but when burned in it the dioxide (TeO_2) is formed. It combines directly with the metals, and with the alkali metals it forms tellurides some of which will dissolve in water. It forms two acids, namely, tellurous acid (H_2TeO_3) and telluric acid ($H_2TeO_4 \cdot 2H_2O$), both of which are crystalline solid compounds. The trioxide (TeO_3) is made by heating telluric acid. Tellurium forms two chlorides, *i.e.*, the dichloride ($TeCl_2$) and the tetrachloride ($TeCl_4$) both of which are crystalline solids. Hydrogen telluride (H_2Te) is made by the reaction of an acid on a telluride and when this takes place the metal itself is precipitated.

The Metal Thallium.—*Its Name.*—The ancient Greeks used the word *thallos* when they meant a *green twig*, and when Sir William Crookes discovered the new metal in 1861 he gave it the name of *thallium* because its spectroscopic line was about the same color as that of a fresh green twig.

Its Occurrence.—Minute particles of the free metal are found in various kinds of pyrites such as are used in making sulphuric acid, and this is its chief source. The only mineral which has this metal as its major con-

stituent is *crookesite*,¹⁰ a selenide of copper, silver and thallium ($Cu, Ag, Tl)_2Se$), which is found at Suraland in Sweden.

Its History.—In 1861 Crookes was making a spectroscopic analysis of the flue dust produced by the roasting of seleniferous pyrites, that is an iron mineral which contains selenium, in the sulphuric acid works at Tilkerode in the Harz mountains in Germany. He observed a bright green line that had not been charted before in the spectra of the various elements. He thought that the element belonged to the sulphur group but Lanry who succeeded in isolating it found it to be a metal and it is this that we now know as thallium.

Its Physical Properties.—Thallium is a bluish-white metal and has a specific gravity of 11.86; it is, therefore, a little heavier than lead, which it closely resembles in many of its properties, and, like the latter, it has practically no tenacity or elasticity. It melts at 301 degrees centigrade, or 574 degrees Fahrenheit, and boils at a white heat.

Its Chemical Properties.—The symbol for thallium is *Tl* and its atomic weight is 204.4. It has been called the *ornithorhynchus paradoxus*¹¹ of the metals because in its properties it stands about halfway between the heavy metals and the alkali metals. In most of its properties it is very like lead but its hydroxide ($TlOH$) exhibits the properties of sodium and potassium. When

¹⁰ Named for Sir William Crookes.

¹¹ So termed from the *ornithorhynchus*, or *duckbill* as it is commonly called. It is the strangest of all living animals being a cross between a bird and a mammal since it has a bill like a duck and lays eggs and has long soft fur on its body.

exposed to air it oxidizes very quickly and when heated in air it gives a purplish vapor.

On placing it in water the oxide on it dissolves and the metal again becomes bright. If left in water for any considerable time the reaction forms the hydroxide ($TiOH$). The metal gives two series of salts and these are (1) *thallic salts*, which are quite like those of aluminum, and (2) *thallous salts*, which resemble those of sodium and silver.

The Metal Tantalum.—*Its Name.*—In Greek mythology Tantalus¹² was a king who was punished for broadcasting by word of mouth the secrets of Zeus.¹³ This castigation was accomplished by placing him up to his chin in a magic lake and hanging tempting fruits around his head. When he tried to sip the water or to get the fruit they both receded from him and so tantalized him to the limit of his mental endurance. The metal was named *tantalum* because it defied all attempts to isolate it for a long time though each chemist who tried to do so thought success was with him.

Its Occurrence.—Tantalum is found with columbium in various rare minerals such as *columbite*, a ferrous columbate ($Fe(CbO_3)_2$); *tantalite*, an iron tantalate which also contains manganese and columbium ($Fe(TaO_3)_2$); and *yttrotalantalite*, which contains columbium, iron, calcium, cæsium, erbium, yttrium, etc. ($YtCoFeCa(CeO_3)_2$). Because tantalum and columbium are so very nearly alike it is very difficult to separate them. These minerals are found in Massa-

¹² This is where we get the word *tantalize*.

¹³ Pronounced *Zds*.

chusetts and South Dakota, but the chief source is Scandinavia and Australia.

Its History.—It was discovered by Ekeberg in 1802 in the mineral that is now known as tantalite, and was isolated in 1820 by Berzelius.

Its Physical Properties.—Tantalum is a silver-white metal and has a specific gravity of 16.8. It has a considerably higher melting point than platinum, namely 2850 degrees centigrade, or 5162 degrees Fahrenheit, while its tensile strength is greater than that of steel.

Its Chemical Properties.—The symbol for tantalum is *Ta* and its atomic weight is 181.5. When heated a little in the air it ignites and forms the pentoxide (Ta_2O_5), and this compound, in turn, combines with the bases when the *tantalates* are produced. The metal resists acids of every kind except hydrofluoric acid and concentrated sulphuric acid.

The Metal Vanadium.—*Its Name.*—The medieval Scandinavians had a goddess whom they called *Feya Vanadis* and when Sefstrom investigated a metal that had been previously discovered but to which no distinctive appellation had been applied, he named it *vanadium* in her honor.

Its Occurrence.—Vanadium is never found free but occurs combined with hydrogen and oxygen as vanadic acid ¹⁴ in various minerals, the two chief ones being *vanadite*, which is a lead chloro-vanadate ($Pb_2(VO_4)_2Cl$), and *carnotite* which is a potassium uranyl vanadate ($K_2O, 2UO, V_2O_5, 3H_2O$), that is potassium, uranium

¹⁴ There are three of these oxyacids of vanadium, namely H_2VO_4 , HVO_3 , and $H_2V_2O_7$.

and vanadium are found together in it. Vanadite comes from Spain, Chile and Argentina, Southwest Africa, Northern Rhodesia, Arizona and New Mexico, while carnotite comes from Colorado and Peru.

Its History.—The metal was discovered by Del Rio in 1801 and investigated by Sefstrom in 1830 and by

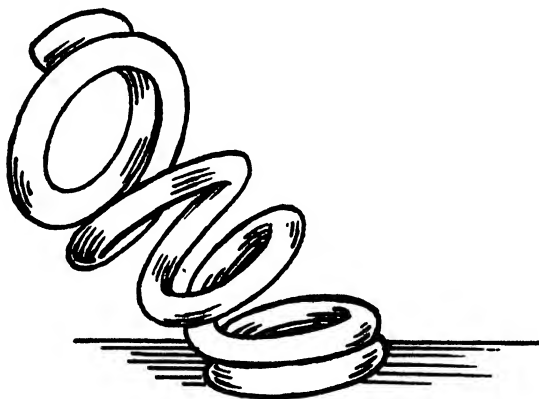


FIG. 23.—A VANADIUM STEEL RAILROAD CAR SPRING

A one-ton weight was dropped on its side from a height of 25 feet. It was bent out of shape but not broken. (Courtesy of Vanadium Corporation of America.)

Wöhler and Berzelius in 1831. It is a very difficult metal to isolate in a pure state but Roscoe succeeded in doing so in 1868.

Its Physical Properties.—Vanadium is a silver-white metal and its specific gravity is 6.03. It melts at about 1750 degrees centigrade, or 3180 degrees Fahrenheit. (See Figure 23.)

Its Chemical Properties.—The symbol for vanadium is *V* and its atomic weight is 51.0. It is not oxidized when exposed to the air and does not react with weak

alkalies, cold sulphuric or hydrochloric acid. It reacts, however, with melted potassium nitrate and forms potassium vanadate. The metal is both basic and acid; it forms five different salts with oxygen, the most stable one being the pentoxide (V_2O_5). When heated with sodium and sodium nitrate, sodium metavanadate ($NaVO_3$) is formed.

The Metal Zirconium.—*Its Name.*—This metal gets its name from the mineral *zircon* and this word, in turn, comes from the Persian root *zargun* which means *yellow* or *golden*, and describes the color of the metal.

Its Occurrence.—Zirconium is only found in combination with other elements. There are several minerals which contain it, the two chief ones being *zircon*, an orthosilicate of the metal ($ZrSiO_4$), and *wöhlerite*, a silicate and columbate of calcium, sodium, zirconium, etc., ($NaCa$)($SiZr$) O_8 . These minerals are widely distributed, being found in Norway, Brazil, and Ceylon.

Its History.—Zirconium was discovered by Klaproth in 1789 in the mineral *zircon*, and it was isolated, though in an impure state, by Berzelius in 1824.

Its Physical Properties.—Zirconium is an allotropic element and exists in three different forms: (a) as an amorphous black powder, (b) as scales of a steel-gray color, and (c) as a gray crystalline metal that bears a close resemblance to cast-iron. The metal has a specific gravity of 6.4 and it melts at 1960 degrees centigrade, or 3560 degrees Fahrenheit. The amorphous form oxidizes when exposed to the air at ordinary temperatures, when the dioxide (ZrO_2) is formed, and in its natural

state this is known as *zirconia*. To make the metallic form combine with the oxygen of the air, it must be brought to a white heat when the dioxide (ZrO_2) is also formed.

CHAPTER VII

THE RARE EARTH METALS

IN chemistry the word *earth* is used to mean the natural oxide of a metal and, it follows, an *earth metal* is one which when combined with oxygen forms an earth, as, for example, *alumina*, which is the oxide of aluminum and from which the metal aluminum is obtained.

The *rare earths* are those which are formed of metals that are not only very scarce but which can only be obtained from them, or *reduced* as it is called, with difficulty; indeed, several of the metals of the rare earths have yet to be had in their free states. These metals are known to exist, however, because they show characteristic lines in the spectrum and because of the way their oxides behave chemically.

History of the Rare Earths and Metals.—The first of the rare earths or oxides of the rare metals was discovered by Gadolin, a Finnish chemist, in 1794, and this he obtained from a heavy black mineral ¹ that came from Ytterby, Sweden. This rare earth, or oxide, formed about two-thirds of the mineral and his experiments showed that in some ways it behaved like calcium oxide and in others like aluminum oxide, or alumina as it is commonly called. Gadolin named the new oxide *yttria* and later on the metal which formed it was given the Neo-Latin name of *yttrium*.

¹ Later on this mineral was given the name of *gadolinite* after Gadolin.

TABLE OF RARE EARTH METALS

<i>Family and Metal</i>	<i>Symbol</i>	<i>Atomic Number</i>	<i>Atomic Weight</i>
The Cerium Family			
Lanthanum	La	57	138.90
Cerium	Ce	58	140.25
Praseodymium	Pr	59	140.92
Neodymium	Nd	60	144.27
Illinium	Il	61	
Samarium	Sa or Sm	62	150.43
Europium	Eu	63	152.0
Gadolinium	Gd	64	157.26
The Yttrium Family			
Terbium	Tb	65	159.2
Dysprosium	Dy	66	162.52
Holmium	Ho	67	163.4
Erbium	Er	68	167.7
Thulium	Tm	69	169.4
Yttrium	Y	39	88.9
Ytterbium	Yb	70	173.6
Lutecium	Lu	71	175.0

The next discovery of a rare earth or oxide was made in 1803 by Berzelius and Hisinger who worked together and Klaproth who worked independently. This new oxide was found in a mineral that came from Bastnäs, Sweden, and to the oxide Klaproth gave the name of *ceria*, while to the metal the Neo-Latin name of *cerium* was given, the reason for which will be explained a little further along. Now while the discoverers of yttria and ceria believed them to be simple compounds, that is that each one consisted of a metal combined with oxygen, it was later shown, as you will presently see, that they contained several new oxides and, it follows, new metals. Thus it came about that those oxides and their metals which occur in *yttria* were placed under one heading

and called the *yttrium family* or *group*, while those which were found in *ceria* were called the *cerium family* or *group*.

Now as the cerium family have the lowest atomic numbers and the lesser atomic weights they were given first place in the table that lists them. You will also please observe that the atomic numbers of the rare earth metals as well as their atomic weights run in arithmetical sequence, that is all of them do so with the exception of yttrium itself, and this metal, as a matter of fact, does not really belong to the family of rare earth metals but has been classed with them by chemists because it is found in the same minerals as the others and behaves like them chemically.

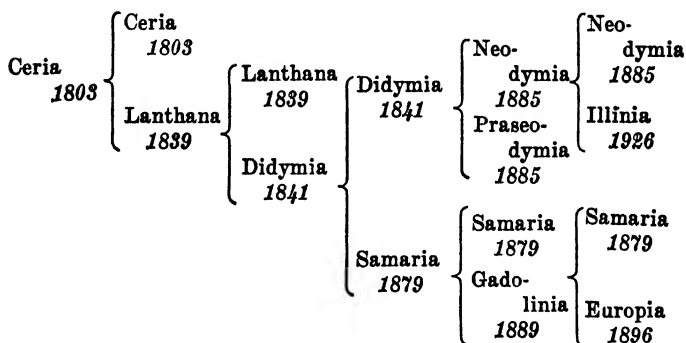
History of the Cerium Family.—Thirty years after Berzelius and Hisinger and Klaproth had discovered cerium, which is to say in 1839, Mosander found that *ceria* contained another oxide and to this he gave the name of *lanthania* and its metal was Latinized to *lanthanum*. Two years later he showed that *lanthania* contained still another oxide and this he named *didymia*.

The next discovery in the line of the cerium family was made by de Boisbaudran in 1879 and this was *samaria*, the natural oxide of *samarium*, which he found in the mineral *samarskite*. Then in 1885 von Welsbach discovered that *didymia* consisted of two oxides and one of these he named *praseodymia* and the other *neodymia*. In 1880 Marignac obtained a new earth in an impure condition and he gave it the provisional name of a *yttria*, that is *alpha yttria*; in 1889

de Boisbaudran recognized that this oxide contained another one and he gave the name of *gadolinia* to it.

In 1896 Demarcy obtained a new oxide from samaria and this he named *europia*. Finally in 1926 Hopkins discovered the last of the rare earth metals *illinium* in the residue of neodymia by means of the X-ray spectral lines of the former. A graphic representation of these successive discoveries is given in the following table:

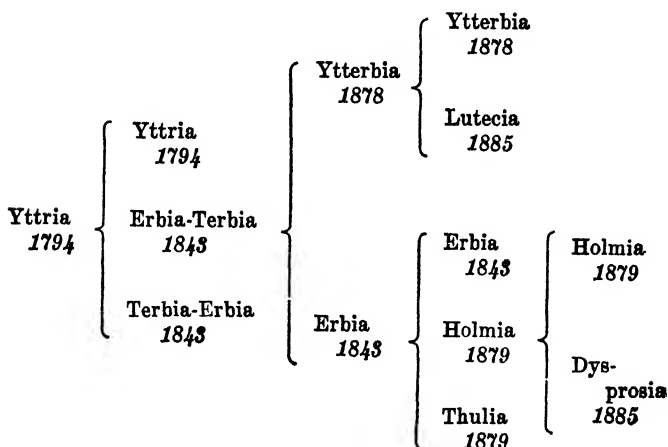
THE DEVELOPMENT OF THE CERIUM GROUP



History of the Yttrium Family.—The *yttria family* or *group* of rare earths or natural oxides and their metals had its beginnings when Gadolin, in 1794, separated the new earth or oxide *yttria* from the mineral gadolinite. The next step was taken by Mosander in 1843 when he found that *yttria* also contained two other oxides which he called *erbia* and *terbia*. Following this research Marignac, in 1878, obtained the oxide *ytterbia*

from erbia and then Soret and Clive in 1879 found that erbia also contained two other oxides and these were named *holmia* and *thulia*. In 1885 Urbain and von Welsbach obtained *lutecia* from ytterbia and, finally, de Boisbaudran separated the oxide *dysprosia* from holmia, all of which is shown graphically in the following table:

THE DEVELOPMENT OF THE YTTRIUM GROUP



THE METALS IN DETAIL

In the following detailed descriptions of the rare earth metals I have listed them alphabetically instead of the way they occur in the first table given in this chapter which is in accordance with the periodic system, or the second and third tables in which they are placed in their historical sequence.

The Metal Cerium.—*Its Name.*—The Latin name for wheat and other grain is *ceres* and the Roman goddess of the wheat fields was in consequence called Ceres. The first of the planetoids was discovered by Piazzi in 1801 and he named it Ceres after the Roman goddess. Then shortly afterwards a new rare earth was discovered by Berzelius and Hisinger and Klaproth and the latter named it *ceria* after the planetoid and the metal was given the Neo-Latin name of *cerium*.

Its Occurrence.—The metal cerium is a constituent of the oxide *ceria* and this latter occurs in various minerals of which *cerite*, which is a complex silicate of cerium and other metals of the rare earth group ($Ce, La, Nd, Pr(SiO_4), H_2O$), is the chief one. It is also found in *monazite*, a phosphate which also contains some of the other cerium group of metals ($(Ce, La, etc.)PO_4$), and in a few other minerals. All of the minerals containing the cerium family of metals are found chiefly in Sweden, the Ural Mountains, Brazil, India, Australia and the United States.

Its History.—The rare earth *ceria* was recognized by Berzelius and Hisinger, and independently by Klaproth in 1803. Mosander obtained the first pure oxide in 1842 and the metal was first isolated by Berzelius.

Its Physical Properties.—The metal cerium looks very much like iron. It has a specific gravity of about 7.0 and a melting point of about 623 degrees centigrade, or 1153 degrees Fahrenheit. It is quite soft, about as malleable and ductile as lead, and a poor conductor of electricity. (See Figure 24.)

Its Chemical Properties.—The symbol for cerium is *Ce* and its atomic weight is 140.13. It is not affected

by dry air but is oxidized by moist air. When cerium is scratched with a piece of steel, or filed, or struck with a piece of flint it throws off a shower of sparks. Cold water has very little effect on it but when immersed in boiling water hydrogen is slowly set free and the metal is oxidized and becomes black. Its chief compound is

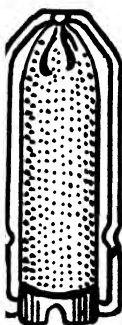


FIG. 24.—A CERIUM (WELLSBACH) GAS MANTLE

ceria, which is cerium oxide (CeO_2) and this is a white, infusible compound.

The Metal Dysprosium.—*Its Name.*—This metal gets its name from the Greek word *dysprositos* and this was compounded from *dys* which means *hard* and *prosos* meaning *to speak with*. It lives right nobly up to its cognomen for it is very hard to speak with, that is, to isolate from its oxide.

Its Occurrence.—Dysprosium is found in very small amounts in the mineral *gadolinite*, which is a silicate of yttrium earths or oxides ($Fe, Yt_2Be_2Si_2O_{10}$); *euxenite*, a tantalate which contains several of the rare earth metals ($(Y, Er, Ce)_2(Ti, Nb)_3Fe(UO)O_{18}$) and *xenotime* which is an yttrium phosphate (YPO_4).

Its History.—Dysprosium was discovered by means of spectral analysis by de Boisbaudran in 1886. Instead of announcing his discovery immediately, he deposited a sealed statement with the Academie des Sciences in which he gave an account of the way he had isolated it from its earth. After he had verified his find the paper was opened and made public. The oxide of the metal was obtained in its pure state by Urbain in 1906.

Its Chemical Properties.—The symbol for dysprosium is *Dy* and its atomic weight is 162.5. It forms a white oxide (Dy_2O_3) and when this is dissolved in an acid it gives the solution a yellowish-green color. It also forms a chloride ($DyCl_3, 6H_2O$); a nitrate ($Dy(NO_3)_3, 5H_2O$); a sulphate ($Dy_2(SO_4)_3, 8H_2O$) and several other salts, and all of which have a slightly yellow color.

The Metal Erbium.—*Its Name.*—When Mosander separated a new oxide from the mineral gadolinite he called it *erbia* from the town of Ytterby, Sweden, where the mineral came from, and the metal was, in consequence, given the Neo-Latin name of *erbium*.

Its Occurrence.—The chief source of erbium is the mineral gadolinite but it is also found in euxenite, xenotime and fergusonite, which latter is a columbate and tantalate of yttrium ($Y, Er, Ce(Cb, Ta)O_4$) and some of the other rare earth metals.

Its History.—Erbia, which is the oxide of the metal erbium, was discovered by Mosander in 1842 in yttria, the oxide of the metal yttrium.

Its Chemical Properties.—The symbol for erbium is

Er and its atomic weight is 167.7. It is not affected by water but dissolves slowly in hot acids when it forms a series of salts that are rose colored, have a sweet, astringent taste and give acid reactions. The oxide (Er_2O_3) is infusible but when it is heated to incandescence it glows with a brilliant green light. Erbium also forms the sulphate ($Er_2(SO_4)_3 \cdot 8H_2O$); the nitrate ($Er(NO_3)_3 \cdot 5H_2O$), and the very soluble double sulphates, erbium with potassium ($Er_2(SO_4)_3 \cdot K_2SO_4 \cdot 4H_2O$), and with ammonium ($Er_2(SO_4)_3 \cdot (NH_4)_2SO_4 \cdot 4H_2O$).

The Metal Europium.—*Its Name.*—This metal was originally given the provisional appellation of the Greek capital letter Σ which is pronounced *Sigma* and is the equivalent of our letter *S*. A little later its discoverer named it *europium* after Europe.

Its Occurrence.—Europium is found in the minerals gadolinite, xenotime and samarskite.

Its History.—In 1889 Crookes observed a new spectral band in some earths he had obtained from gadolinite and samarskite and believing it to be due to a new metal he called it Σ . Then in 1896 he obtained the oxide of a new metal from the same minerals and this he named *europium*. It was found later on that Σ and europium were one and the same metal. The oxide of this metal was first obtained in its pure state by Urbain and Lacombe in 1904.

Its Chemical Properties.—The symbol of europium is *Eu* and its atomic weight is 152.0. The metal itself has not yet been isolated but its various compounds have been obtained. Its chief compounds are its oxide (Eu_2O_3), which is a pale pink powder; its chloride

($EuCl_3$); its hydroxide ($Eu(OH)_3$); its oxychloride ($EuOCl$); its carbonate ($Eu_2(CO_3)_3$) and, finally, its sulphate ($Eu_2(SO_4)_3 \cdot 8H_2O$).

The Metal Gadolinium.—*Its Name.*—This metal was named in honor of John Gadolin, the Finnish chemist, by de Boisbaudran.

Its Occurrence.—Gadolinia, which is the oxide of the metal gadolinium (Gd_2O_3) is found in the mineral *gadolinite* [$(Y, Ce, La, Nd, Pr, Di)_2 Be_2 Fe Si_2 O_{10}$] which is also found in monazite, samarskite, which is a columbate and tantalate of iron, calcium, uranium and some of the rare earth metals [$(Fe, Ca, U)_2 (Ce, Di, La, Yt, Er)_2 Cb, Ta_2 O_2$] and also in Norwegian ytterspar.

Its History.—The history of gadolinium goes back to 1880 when Marignac found a new earth and gave it the provisional appellation of a *yttria*, that is, *alpha yttria*. The metal was definitely discovered by de Boisbaudran in 1889.

Its Chemical Properties.—The symbol of gadolinium is *Gd* and its atomic weight is 157.26. The metal forms a white oxide (Gd_2O_3) and this has the property of absorbing carbon dioxide from the air. It dissolves easily in acids and its salts are colorless. Its chief salts are the chloride ($GdCl_3 \cdot 6H_2O$), the sulphate ($Gd_2(SO_4)_3 \cdot 8H_2O$) and the nitrate ($Gd(NO_3)_3 \cdot 6H_2O$), and these are the least soluble of the entire earth series.

The Metal Holmium.—*Its Name.*—This metal gets its name from *Holmia*, the Latinized form of *Stockholm*, in the neighborhood of which the minerals that contain it are found.

Its Occurrence.—There are several minerals that contain holmium, the chief ones being gadolinite, xenotime,

euxenite, orthite, which is a silicate having several of the rare earth metals in it, and comes from Hittero and Ytterby.

Its Chemical Properties.—The symbol of holmium is *Ho* and its atomic weight is 163.5. The metal itself has not yet been isolated and its chemical properties are so like dysprosium that its elemental character was long a matter of doubt. The earlier samples of its oxide contained large amounts of dysprosium and so the later and purer products are called *neo-holmia*. The oxide of holmium (Ho_2O_3) has a yellowish color and dissolves in many acids when it forms salts that have an orange-yellow color. The salts of holmium have a high magnetic susceptibility. The other chief compounds of holmium are the carbide (Ho_4C_3), the chloride ($HoCl_3$), the hydroxide ($Ho(OH)_3$), the nitrate ($Ho(NO_3)_3$) and the sulphate ($Ho_2(SO_4)_3$).

The Metal Illinium.—*Its Name.*—This metal was named *illinium* after Illinois by Hopkins, its discoverer, who is a professor of chemistry at the University of Illinois. The metal itself has never been isolated and, it follows, there is no information available concerning its properties or even its atomic weight. It is perfectly safe to assume, however, that it fits in closely with the other members of the rare earth group.

In a recent letter from Dr. Hopkins to the present author he states that during the last six years he and his assistants have been working industriously in an attempt to increase the knowledge concerning illinium. They have attempted to concentrate the illinium from a quantity of rare earth material which represents 5 or 6

tons of monazite sand. A checkup brings the estimate that their effort has brought together about 10 grams of illinium, and this is still far from being free from other rare earths.

It seems quite certain that illinium is one of the three or four rarest metals that are now known. The difficulties of obtaining workable quantities are increased very materially by the fact that it is always associated with the other members of the rare earth group which are so very much more abundant.

The Metal Lanthanum.—*Its Name.*—The ancient Greeks had the word *lanthanos* for anything that was *concealed*, and as the new metal was so well concealed that it was difficult to isolate, Mosander gave it the name of *lanthanum*.

Its Occurrence.—It is found in the oxide of earth that is associated with the cerium metals in cerite, monazite, and orthite, and it is also found in *lanthanite* as a carbonate ($La_2(CO_3)_3 \cdot 9H_2O$), which latter mineral occurs in Lehigh County, Pennsylvania, and Essex County, New York.

Its History.—It was discovered in 1839 by Mosander and isolated by him in the form of numerous fine globules which had the appearance of a powder. Hillebrand and Norton obtained the metal in mass form in 1879.

Its Physical Properties.—Lanthanum is a lead-gray metal whose specific gravity is 6.16. It is fairly ductile and malleable and has a melting point of about 810 degrees centigrade, or 1490 degrees Fahrenheit.

Its Chemical Properties.—The symbol for lanthanum is *La* and its atomic weight is 138.9. It oxidizes

quickly when exposed to air and decomposes water slowly when the latter is cold and rapidly when it is hot. It dissolves in nearly all acids and with them forms salts, most of which are colorless and have an astringent taste.

Its chief compound is the oxide (La_2O_3), which has a white color and is the strongest base of the group; when this is slacked with water it gives the hydroxide ($La(OH)_3$). Its chloride ($LaCl_3$) is very soluble in water, and forms double salts with chlorides of gold and platinum. Then there is the nitrate ($La(NO_3)_3 \cdot 6H_2O$); the oxalate ($La_2(C_2O_4)_3$) which is more or less hydrated; the carbide (La_4C_3) which is decomposed by water and gives a mixture of acetylene and methane gases; and, lastly, the nitride (LaN).

The Metal Lutecium.—*Its Name.*—The Latin word for *muddy* is *luteus* and because the river that we know as the Seine was turbid, the ancient Romans called the chief settlement that stood on its banks *Lutetia*, which in more recent times became Paris. As the discoverer of the rare metal now under consideration was a Frenchman, he gave it the Neo-Latin name of *lutecium*.

Its Occurrence.—Lutecium is found in about all of the minerals which contain yttrium, namely, gadolinium, xenotime, polycrase and bloomstrandine. These minerals are the chief sources of lutecia, which is the oxide containing the metal, but the amounts in them are very small.

Its History.—Marignac separated lutetia from the erbium earths in 1878. Then in 1907 Urbain and in 1908 von Welsbach explained how ytterbia could be divided into two distinct elements, and the latter wanted

to name one of them *aldebaranium* after *Aldebaran*, a star of the first magnitude in the eye of *Taurus*, and the other *cassiopeium* after *Cassiopeia*, one of the northern constellations.

Since Urbain separated out these two earths first he was really the discoverer of the new metals and to the first of them he gave the name *neo-ytterbium* or just *ytterbium* as it is now called, and to the second one *lutecium* and these are the names they have since been known by.

Its Chemical Properties.—The oxide of lutecium (Lu_2O_3) reacts with the various acids and forms colorless salts, the two chief ones being the chloride (LuCl_3) and the sulphate ($\text{Lu}_2(\text{SO}_4)_3 \cdot 8\text{H}_2\text{O}$)

The Metal Neodymium.—*Its Name.*—The Greek word for *new* is *neos* and that for *twin* is *didymos*. The new metal was named *neodymium* because it was the second of a pair of elements that were discovered at the same time in the earth that had been known as *didymia*, the other twin metal being *praseodymium*.

Its Occurrence.—Neodymium is found in all of the minerals which contain cerium and lanthanum but its chief source is cerite.

Its History.—For a long time after its discovery the rare earth ceria was thought to be, simply, the oxide of the metal cerium but Mosander disproved this idea in 1839 when he showed that it was quite a complex compound and separated from it two new oxides and these were *lanthania* and *didymia*. Then von Welsbach in 1885 found further that *didymia* was formed of the oxides of two other new metals and the latter he named *praseodidymium* and *neodidymium*, both of

which were quickly shortened to *praseodymium* and *neodymium*.

Its Physical Properties.—Neodymium is a white, lustrous metal with a yellowish tinge; its specific gravity is 6.95 and its melting point is 840 degrees centigrade, or 1744 degrees Fahrenheit.

Its Chemical Properties.—The symbol for neodymium is *Nd* and its atomic weight is 144.27. It is not oxidized when exposed to air. It reacts slowly with cold water and quickly with hot water. It absorbs hydrogen and its salts have a rose-red color. Its chief compounds are the oxide (Nd_2O_3), the hydroxide ($Nd(OH)_3$), the chloride ($NdCl_3$), the fluoride (NdF_3), the carbide (Nd_4C_3), the sulphate ($Nd_2(SO_4)_3$), and the sulphide (Nd_2S_3).

The Metal Praseodymium.—*Its Name.*—This metal gets its name from the Greek roots *prasios* which means *green* and *didymos* meaning *twin*, and it is so called because its salts have a green color and it was discovered at the same time as neodymium.

Its Occurrence.—Praseodymium is found in all of the minerals that have cerium and lanthanum in them but to a lesser extent.

Its History.—The history of praseodymium parallels that of neodymium which has just been described.

Its Physical Properties.—Praseodymium is a white metal with a slightly deeper yellow tinge than its twin neodymium, and its specific gravity is 6.60. It melts at about 940 degrees centigrade, or 1724 degrees Fahrenheit, and when heated in air it ignites at 290 degrees centigrade, or 554 degrees Fahrenheit.

Its Chemical Properties.—The symbol for praseo-

dymium is *Pr* and its atomic weight is 140.92. It does not oxidize when exposed to dry air but does when subjected to moist air. It absorbs hydrogen and its salts have, in general, a green color. Numerous compounds have been produced with it and chief among these are its oxide (Pr_2O_3); its hydroxide ($Pr(OH)_3$); its chloride ($PrCl_3$), which is formed of bluish-green needle-like crystals, its carbonate ($Pr_2(CO_3)_3 \cdot 8H_2O$), which is formed of silky green scales; its fluoride (PrF_3), a gelatinous precipitate, which when warmed forms a mass of yellow glistening crystals and these take on a green color when viewed by reflected light; the hydride (PrH_3); the sulphate ($Pr_2(SO_4)_3$) and, lastly, the sulphide (Pr_2S_3).

The Metal Samarium.—*Its Name.*—There was once a Russian mining engineer who bore the cognomen of Samarski and the mineral known as *samarskite* was named for him. As the new metal was found in this mineral its discoverer called it *samarium*.

Its Occurrence.—Samarium is found in various minerals that contain the cerium earths but when the metal itself is wanted the chief sources are cerite, allanite, euxenite and samarskite.

Its History.—The metal samarium was discovered with the aid of the spectroscope by de Boisbaudran in 1879. In the same year he separated its oxide samaria from that of didymia and then isolated the metal by electrolysis.

Its Physical Properties.—Samarium is a whitish metal and its specific gravity is 7.7 to 7.8. It is very brittle, has the hardness of steel, and melts at 1350 degrees centigrade, or 2462 degrees Fahrenheit.

Its Chemical Properties.—The symbol for samarium is *Sa* or *Sm* as you like it, and its atomic weight is 150.43. It oxidizes quickly in air and becomes coated with a yellow film. The chief compounds of samarium are its oxide (Sm_2O_3), its chloride ($SmCl_3$), its hydroxide ($Sm(OH)_3$), its nitrate ($Sm(NO_3)_3 \cdot 6H_2O$), its sulphate ($Sm_2(SO_4)_3$) and its sulphide (Sm_2S_3).

The Metal Terbium.—*Its Name.*—When Mosander separated the new oxide from that of yttria, he gave it the name of *terbia* in honor of the town Ytterby in Sweden, and the metal was given the Neo-Latin name of *terbium*.

Its Occurrence.—Terbium occurs in the same minerals as *erbium*.

Its History.—In 1842 Mosander separated the oxide of erbium from that of yttrium but when other chemists tried to do so they failed and they used the name to denote an oxide that had a rose-red color. Then in 1887 Delafontaine succeeded in getting the oxide that Mosander had obtained nearly half a century before and which he called *erbia*; since that time this name has been applied to the original oxide while that discovered by Mosander and Delafontaine has come to be known as *terbia*. In other words, *erbia* became known as *terbia* and *terbia* as *erbia*.

Its Chemical Properties.—The symbol for terbium is *Tb* and its atomic weight is 159.2. Its chief compounds are its oxide (Tb_2O_3), its hydroxide ($Tb(OH)_3$), its chloride ($TbCl_3$) and its nitrate ($Tb(NO_3)_3 \cdot 6H_2O$).

The Metal Thulium.—*Its Name.*—The discoverer of this new metal named it *thulium* which is the Neo-

Latinized version of *Thule*, an ancient name for Scandinavia.

Its Occurrence.—It is found in euxenite, xenotime and a few other minerals.

Its History.—Thulium was discovered by Cleve in 1897 while he was trying to find out what gave the rose color to the salts of erbium.

Its Chemical Properties.—The symbol for thulium is *Tm* and its atomic weight is 169.4. The salts of thulium are green and its chief compounds are the oxide (Tm_2O_3), which is a dense white powder; the hydroxide ($Tm(OH)_3$); the chloride ($TmCl_3 \cdot 7H_2O$); the nitrate ($Tm(NO_3)_3 \cdot 4H_2O$), and the sulphate ($Tm_2(SO_4)_3 \cdot 8H_2O$).

The Metal Ytterbium.—*Its Name.*—This metal also gets its name from the town of Ytterby, Sweden.

Its Occurrence.—It occurs in practically all of the minerals that contain yttrium.

Its History.—The earth or oxide of ytterbium was first obtained by Marignac in 1878 from erbia, the erbium earth or oxide, and it was thought to be an element until 1905 when von Welsbach showed by means of the spectroscope that it was a complex substance. Then in 1907 Urbain separated it into two oxides and one of these he named *neo-ytterbium* and the other *lutecium*; the former metal is now called simply *ytterbium*.

Its Chemical Properties.—The symbol for ytterbium is *Yb* and its atomic weight is 173.6. It forms colorless salts and its chief compounds are its oxide (Yb_2O_3), its hydroxide ($Yb(OH)_3$), its chloride ($YbCl_3 \cdot 6H_2O$), its carbonate ($Yb_2(CO_3)_3 \cdot 4H_2O$); its

nitrate ($Yb(NO_3)_3 \cdot 8H_2O$), its bromide ($YbBr_3 \cdot 8H_2O$), its sulphate ($(Yb_2SO_4)_3 \cdot (8H_2O)$, and several phosphates.

The Metal Yttrium.—*Its Name.*—I have already explained in the early part of this chapter that the metal yttrium was named after the town of Ytterby, Sweden, because it was from this place that the mineral gadolinite, in which it occurs, was found.

Its Occurrence.—Yttrium is found in practically all of the rare earth minerals but its chief source is gadolinite, euxenite, xenotime, polycrase and samarskite.

Its History.—The oxide of this metal was discovered by Gadolin in 1794 and the metal itself was isolated from it by Wöhler in 1828.

Its Physical Properties.—Yttrium is a lustrous powder having an iron-gray color when freshly obtained and comes in the form of small scales. Its specific gravity is 3.8 and it melts at 1490 degrees centigrade, or 2714 degrees Fahrenheit.

Its Chemical Properties.—After yttrium has been kept for some time its color becomes darker and this is not due to oxidation but to the photo-chemical action of light upon it. It oxidizes quickly in air and when burnt in air it is converted into the oxide (Y_2O_3), while if placed in water it is changed into the hydroxide ($Y(OH)_3$).

The salts produced by yttrium are colorless and its chief compounds are the chloride ($YCl_3 \cdot 6H_2O$), the carbonate ($Y_2(CO_3)_3 \cdot 3H_2O$), the nitrate ($Y(NO_3)_3$), the bromide ($YBr_3 \cdot 9H_2O$), the fluoride ($YF_3 \cdot \frac{1}{2}H_2O$), the sulphate ($Y_2(SO_4)_3$), the sulphide (Y_2S_3), and various yttrium phosphates.

CHAPTER VIII

THE RADIOACTIVE METALS

THE most marvelous discovery of the nineteenth century was that of the radioactive metals and their compounds. By *radioactive metals* are meant those that disintegrate, send out rays and are transformed into other elements, and which by virtue of these properties behave physically in ways that are entirely different from those of the other known metals and their compounds.

How Radioactivity Was Discovered.—*The Geissler Tube.*—Now to begin at the very beginning of radioactivity, a German instrument maker named Geissler made the first vacuum tube (see *Figure 25*), which

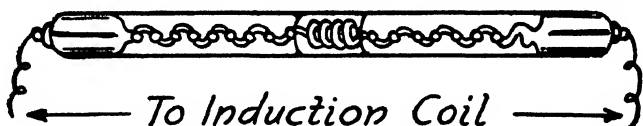


FIG. 25.—A GEISSLER TUBE

has ever since been known as the *Geissler tube*. This tube, which he invented in 1850, has a wire electrode sealed in each end and the air is partly pumped out of it at the time of sealing. Now when this low vacuum tube is connected with a spark coil the tube will glow with a soft radiant light.

The Crookes Tube.—About 1875 Sir William Crookes, an English scientist, made tubes of various

shapes and with an improved air-pump he was able to exhaust them to a much higher degree than Geissler did his tubes, with the result that the molecules of air or gas which still remained in them had free play and so exhibited various new properties. Thus when one of the *Crookes tubes*, as they are called, is connected with a spark coil the negative electrode, or *cathode*, projects forth a stream of *cathode rays*, and this is formed of particles of negative electricity, or *electrons* as they are now known.

The Discovery of the X-Rays.—It is now almost thirty-five years since Professor Wilhelm Röntgen, a German physicist, discovered that when a Crookes tube was energized by a spark coil it would set up *outside of it* rays that had the power to pass through black paper, wood and flesh but which were stopped by bone, the metals and other dense substances, and, further, they acted on a photographic plate like light waves.

Röntgen did not know what these penetrative rays consisted of and so he called them *X-rays*. It is now well known that they are waves in and of the ether exactly like light waves except that they are a thousand times shorter than the shortest light wave. These exceedingly short waves are set up by the electrons that are shot forth from the cathode of a Crookes tube, or X-ray tube as it is now called, when they strike the hard piece of metal which forms the anode, and the waves that constitute the X-rays are projected from it and pass through the tube as shown in *Figure 26*.

The Discovery of the Becquerel Rays—Almost as soon as Röntgen discovered the penetrative power of the X-rays, physicists and chemists the world over began

to test various minerals, the compounds of metals and the metals themselves in order to find out if there was any kind of a substance which would give out rays of a like nature. Then in 1897 Henri Becquerel, of France, found that uranium ores gave out rays that would pass through black paper and affect a photo-

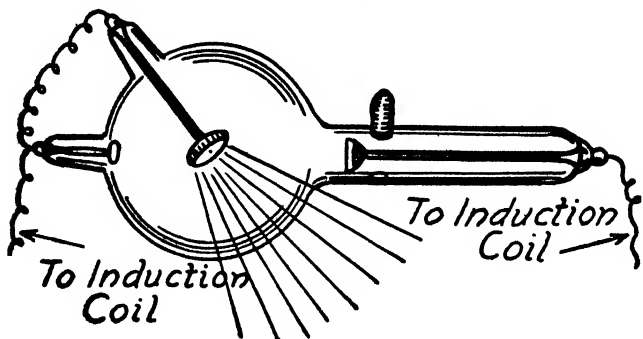


FIG. 26.—AN X-RAY TUBE

graphic plate, though, of course, they were much more feeble than those set up by an X-ray tube. These new rays were called *Becquerel rays* after their discoverer.

The Discovery of Radium Rays.—A year after Becquerel discovered the rays that bear his name, that is to say, in 1898, Madame Curie and Professor Schmidt, who were working independently of each other, found that the salts of thorium produced rays like those of uranium. Then in the same year Madame Curie separated the first radioactive substance from the mineral which contained it and this she named *polonium* after her native country, Poland. This metal which has not yet been isolated, appeared in the precipitate which she obtained while she was trying to isolate radium, along with bismuth to which it is chemically related,

and so Meyer and Schwindler called it *radioactive bismuth*; the precipitate also contained *tellurium* and Markwald called it *radio-tellurium*.

Next Monsieur and Madame Curie discovered that the mineral *uraninite*, or *pitchblende*¹ as it is called, which is made up chiefly of uranium oxide (U_3O_8), emitted rays that were far more active than those of uranium alone. This fact led them to believe that there was some other element in pitchblende which set up these very powerful rays and after a long series of chemical operations they separated a metal from it that was a thousand times more active than that of uranium and this they called *radium*. The way in which they did this is explained in *Part II of Chapter XIV*.

The Metal Uranium.—Its Name.—In both Greek and Latin the word *uranus* means the sky and in Greek mythology *Uranus* was the personification of Heaven. When Herschel discovered a new planet on the frontier of the solar system in 1781, he named it *Georgium Sidus* in honor of King George III. The astronomers of his time, however, preferred to call it Herschel after its discoverer, but later on Bode suggested the name of *Uranus* to match it up with the names of the other planets which were derived from classical mythology and it has been so called ever since. When the new metal was discovered by Klaproth a few years later he named it *uranium* after the planet *Uranus*.

Its Occurrence.—*Uranium* is found chiefly in pitchblende as the oxide (U_3O_8) together with smaller

¹ This mineral is called *pitchblende* because it has a black pitch-like luster.

amounts of several other metals. It is also found in carnotite, which is a uranite and vanadate of potassium ($K_2O, 2UO_3, V_2O_5, 3H_2O$). Pitchblende comes from Bohemia and Cornwall, England, and carnotite from Colorado.

Its History.—The oxide and, it follows, the metal, was discovered by Klaproth in 1789 but the metal itself was not isolated until 1842 when Peligot obtained it in its free state.

Its Physical Properties.—Uranium is a nickel-white metal and has a specific gravity of 186.85 and it is therefore the heaviest of all the elements. It is malleable, softer than steel and melts at about 1850 degrees centigrade, or 3362 degrees Fahrenheit. It sets up alpha rays, beta rays and gamma rays² and all of these will be described more fully as we push along. It disintegrates and after passing through four transformations is changed into radium. In these transformation states the *uranium* is changed into *uranium X1*; this into *uranium X2*, this into *uranium 2*, and this into *radium*, and all of which is shown in the accompanying diagram, *Figure 27*.

Its Chemical Properties.—The symbol for uranium is *U* and its atomic weight is 238.2 The metal is chemically very active and reacts vigorously with the halogens. It oxidizes very slowly in air at ordinary temperatures but it burns readily in oxygen when heated to 170 degrees centigrade, or 338 degrees Fahrenheit and forms the oxide (U_3O_8). It dissolves in mineral acids and acts as an acid and as such pro-

² These rays are named after the first three letters of the Greek alphabet.

duces *uranous salts* as, for example, the peroxide (UO_4); it also acts as a basic element which gives *uranyl salts*, such as uranyl chloride (UO_2Cl_2), and the *uranates* which result when the oxide (UO_3) combines with strong bases.

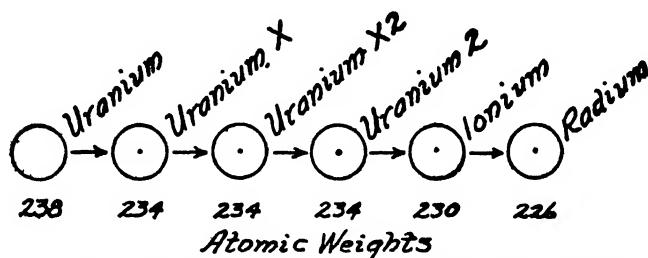


FIG. 27.—THE TRANSFORMATION OF URANIUM INTO RADIUM

The Metal Radium.—*Its Name.*—We get the word *radium* from that of *ray*, which means *a line* that is projected from one point to another point and this, in turn, from the Latin root *radius*, which means *the spoke of a wheel*.

Its Occurrence.—The metal radium is found in small quantities in the mineral uranite, or pitchblende (U_3O_8), and in carnotite ($K_2O, 2UO_3, V_2O_5, 3H_2O$), and it is chiefly from these sources that it and its compounds are obtained.

Its History.—The history of radium has already been given under the caption *The Discovery of Radium Rays*.

Its Physical Properties.—The metal radium when pure has the color and luster of silver, and its atomic weight is 225.95, and it is, therefore, the third heaviest metal. Radium has a melting point of 700 degrees centigrade, or 1290 degrees Fahrenheit. Now radium

is different from the ordinary metals in that (1) it ionizes the air around it, (2) has a higher temperature, about 1.5 degrees centigrade, or 2 degrees Fahrenheit, than the air surrounding it, (3) sets up and sends out rays, (4) produces physiological changes, and (5) disintegrates and changes into other elements.

Its Property of Ionization.—By *ionization* is meant that the air is changed from a nonconductor to a con-

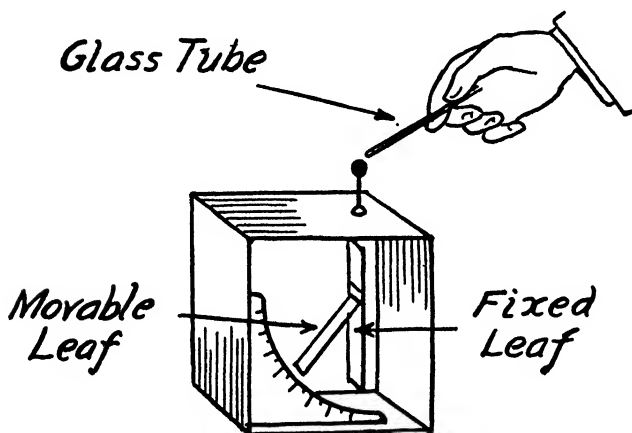


FIG. 28.—AN ELECTROMETER FOR THE DETERMINATION OF RADIO-ACTIVE METALS

ductor of electricity. This fact was discovered by Becquerel by means of an *electrometer*, an instrument formed of a pair of gold leaves supported at one end³ as shown in *Figure 28*. Now when he held a crystal of the salt of uranium near the electrified leaves of the electroscope, which were, in consequence, spread

³ An electrometer is easily made and you will find a detailed description of it in my *Book of Electricity* published by D. Appleton and Company, New York.

apart, they at once collapsed. This action was brought about by the radioactive salt ionizing the air around the free end of the rod and thus permitting the electric charge to escape. The electroscope, then, provides an easy and sensitive way to tell whether a substance is radioactive and, further, the degree of its activity.

Its Property of Producing Heat.—One of the first things that the Curies learned about radium was that the metal and its salts always maintain a temperature of about 1.5 degrees centigrade, or 2 degrees Fahrenheit, higher than that of the air around it. In other words, a given amount of it will give off enough heat to raise an equal weight of water from the freezing to the boiling point in one hour. Thus radium is constantly doing work without any external supply of energy.

Its Physiological Properties.—Becquerel discovered that the radioactive rays have a pronounced effect on the tissues of the human body. He carried some uranium salts in a small bottle in an inside vest pocket and both to his surprise and dismay he found some six hours later that the rays had burned his flesh and made sores which took several weeks to heal. Later on, Dandos, a Parisian physician, discovered that these radioactive rays had a healing action in cases of lupus and other malignant growths.

Its Property of Emitting Rays.—The radioactive properties of radium in ionizing the air, reducing the silver salts of a photographic plate, producing phosphorescence and fluorescence, and other phenomena are all due to the rays it gives off. Now, as I have said before, there are three kinds of rays given off by radium

and its compounds and these are known as (1) the alpha rays, (2) the beta rays, and (3) the gamma rays. The nature of these rays was discovered in 1902 and 1903 by Rutherford who sifted them out by passing them through a powerful magnetic field as shown in *Figure 29*. The alpha rays are bent in one direction, the

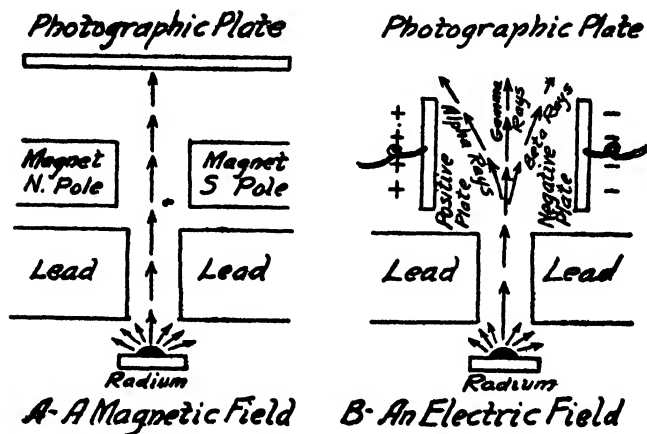


FIG. 29.—SIFTING RADIUM RAYS BY A MAGNETIC AND AN ELECTRIC FIELD

beta rays are bent in the other direction, while the gamma rays are not bent at all.

The *alpha rays* are formed of atoms of helium ⁴ gas and each of these carries a positive charge of electricity. These atoms travel at a speed of about 20,000 miles per second or a little more than one-tenth as fast as light. The heat that is set up by the radium is produced by the atoms of the alpha rays colliding with

⁴ This remarkable result is the first case discovered in which one stable element has been known to be transformed into another one.

others of a like kind and, further, when they strike certain substances, as for example, zinc sulphide, they make it luminous. The ionizing effect of the rays on air is also chiefly due to the alpha atoms. The alpha rays are not very penetrating for they are stopped by a sheet of paper or by aluminum foil that is 0.1 of a millimeter thick.

The *beta rays* are formed of minute charges of negative electricity, or *electrons* as they are called, and these are shot forth from the metal and travel at a speed very nearly equal to that of light, namely, 186,300 miles per second. The beta rays are nearly 100 times more penetrating than the alpha rays and will pass through, for the most part, gold and sheet aluminum that is $\frac{1}{4}$ of an inch thick.

The *gamma rays* are exactly like light waves except that they are 1000 times shorter than the shortest wave length of light. The gamma rays are able to penetrate metals of considerable thickness and many other kinds of materials.

Its Property of Disintegration.—Since it is the atoms of radium that give out the alpha and beta rays, it follows that there must be a corresponding amount of energy expended and that the radium atoms must disintegrate, that is, break up into their constituent particles of matter. This action is due to the instability of the radium atom and as the breaking up of it continues to go on after the expulsion of the particles of which the rays are formed, the radium atom will be less stable than before. If this is true, about half of the particles of a given mass of radium will break up

in about 2000 years. The supply of radium is not exhausted, however, because it is constantly being formed by the breaking up of uranium.

Its Property of Transformation.—Before radium was discovered scientists believed that all of the elements had existed as such ever since the beginning of time, that they could not be changed in any way and that they would continue to exist until the end of time. Now the radium that exists at the present time was not always radium, neither will it always be radium, for just as it has been made by the disintegration and transformation of uranium so, also, it is being slowly changed into other elemental forms the end-product of which is lead.

It is not only known that uranium is being transformed into radium and that, in turn, the latter is being transformed into lead, but that the metal potassium is radioactive to a small degree, and this tends to show that all of the elements may be changing to still other elements, but the rate of change in them is so slow that no way has yet been devised to prove it. This brings us right back to the belief of the medieval alchemists that one element can be changed into another one and that the time may yet come when the baser metals can be changed into the noble ones.

Under the subcaption of *Its Physical Properties*, I have shown how uranium is transformed in four stages into radium and now continuing the process I shall point out how radium is transformed in nine stages into lead. Starting then with radium this is transformed first into *radium emanation*, or *niton* as

Ramsey called it, but which has recently been renamed *radon*⁵ to indicate its source.

Radon changes into *radium A*, this into *radium B*, this into *radium C*, this into *radium D*, this into *radium E*, this into *radium F*, which is the element

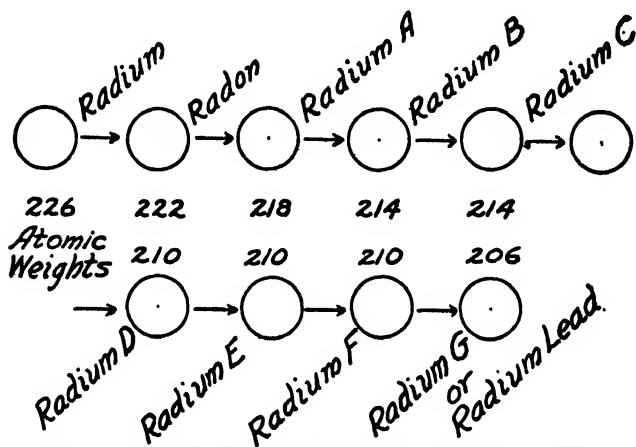


FIG. 30.—THE TRANSFORMATION OF RADIIUM INTO LEAD

polonium,⁶ and this finally changes into *lead*, all of which is shown in the diagram *Figure 30*.

The lead which is the end product is exactly like ordinary lead in all respects except that it is not quite as heavy, and it is therefore an *isotope* of lead, which means that its chemical behavior is the same as ordinary lead but that there is a small difference in their atomic weights.

Its Chemical Properties.—The symbol for radium is *Ra* and its atomic weight is 222.95. It oxidizes

⁵ Radon is a heavy gas and belongs to the family of inert gases. It is an element with an atomic weight of 222.

⁶ The first radioactive substance discovered by Mme. Curie, and named by her in honor of her native country of Poland.

rapidly in air, decomposes water energetically and dissolves in it forming the hydroxide. It also dissolves in all acids, taking the place of the hydrogen in them and setting it free when its salts are formed. Its chief compounds are its oxide (RaO_2); its hydroxide ($Ra(OH)_2$); its chloride ($RaCl_2$); its bromide ($RaBr_2$); its nitrate ($Ra(NO_3)_2$); its carbonate ($RaCO_3$), and its azide ($Ra(N_3)_2$) which is formed by the replacement of the hydrogen of hydrazoic acid by the metal. Radium is usually sold in the form of the bromide or the chloride and these are often mixed with the corresponding salts of barium.

The Metal Thorium.—*Its Name.*—In Norse mythology *Thor* is the great god of thunder, and the metal *thorium* was named after him because it was found in the mineral thorite which occurs in Scandinavia.

Its Occurrence.—While thorium is found in *thorite*, which is a thorium silicate ($ThSiO$), most of it is obtained now from monazite sand which occurs in Sweden, Greenland and the United States.

Its History.—The metal *thorium* was discovered in thorite by Berzelius in 1828, and in 1898 Professor Schmidt and Madame Curie found that the salts of the metal emitted rays like the Becquerel rays from uranium.

Its Physical Properties.—Thorium is a grayish-white metal and is very heavy, having a specific gravity of 12.16. It is about as hard and ductile as platinum and has a melting point of 1700 degrees centigrade, or 3092 degrees Fahrenheit. Like radium the metal thorium and its compounds give out three kinds of

rays, *i.e.*, alpha rays, beta rays and gamma rays, and in its transformation it produces a long series of substances. In these transformations *thorium* is changed into *thorium 1*, or *mesothorium*, as it is called; this into *thorium 2*, or *mesothorium 2*; this into *thorium X*; this into *thorium emanation*; this into *thorium A*; this into *thorium B*; this into *thorium C*, and finally, this into an end product which is an isotope of *lead*.

Its Chemical Properties.—The symbol for thorium is *Th* and its atomic weight is 232.12. When heated in air it burns with a bright flame, throwing out a shower of sparks, and forming the oxide (ThO_2) or *thoria* as it is called. It slowly dissolves in all the common acids except hydrochloric acid and *aqua regia*, but it does not react with the alkalies. Its compounds are analogous to zirconium.

Other Radioactive Metals.—There are a few other radioactive metals and chief among these are actinium, polonium, ionium and potassium.

Actinium is a hypothetical metal and it has not yet been fully investigated. Its symbol is *Ac*, the atomic number 89 has been assigned to it, and its atomic weight is believed to be in the neighborhood of 230. It was discovered by Debierne in 1898 in the mineral pitchblende. A definite spectrum of it has not yet been obtained but its chemical properties show that it is analogous to thorium.

Like radium it gives off three kinds of rays and these are α , β and γ , *i.e.*, alpha, beta and gamma rays. Its transformation gives *radioactinium*; this gives *actinium X*; this gives *actinium A*, which does not give out

rays, and this changes into *actinium B*, which is active and gives out rays.

Polonium is also a hypothetical metal. Its symbol (if it has one) is *Po* and its atomic weight is believed to be about 210. It was discovered by Madame Curie, in 1898, in pitchblende, and named *polonium* after Poland where she was born. It is not nearly as active as radium and emits only the α -rays. It is probably an isotropic form of *radium F*. Chemically, it is closely related to bismuth and still closer to tellurium.

Ionium is likewise a hypothetical metal. Its symbol is *Io* and its atomic weight is believed to be about 230. It was discovered by Boltwood in 1907 in the rare earths and is also found in the mineral carnotite. It is the fourth transformation product of uranium and it is this element, *i.e.*, ionium, that changes directly into radium.

Potassium and *rubidium* have been discussed in the chapter on the alkali metals and all that need be said about them here is that they are slightly radioactive.

CHAPTER IX

THE HYPOTHETICAL METALS

A *hypothetical metal* is one which is believed to exist but which has never been isolated. Now there are three classes of hypothetical metals and these are (1) true hypothetical metals, (2) pseudo-hypothetical metals, and (3) mythical hypothetical metals.

A *true hypothetical metal* is one which by every known test, such as its spectral lines, and its chemical reactions, shows that it really exists; a *pseudo-hypothetical metal* is one which has been proved to be (a) a substance that has the properties of a new metal, (b) a mixture of some of the metallic oxides, or (c) a metal that has previously been discovered. Finally, a *mythical hypothetical metal* is one that has little or no scientific evidence to show that it exists and which, as a matter of fact, does not exist.

The Hypothetical Metal Ammonium.—As you probably know, ammonia (NH_3) is a colorless gas and, as its formula shows, each of its molecules is made up of 1 atom of nitrogen and 3 atoms of hydrogen. Now ammonia (NH_3) and water (H_2O) have a great affinity for each other and when the former is dissolved in the latter they react with each other and one of the atoms of the hydrogen of the water combines with those of the hydrogen of the ammonia and a new compound is formed that has the formula NH_4OH .

The molecule NH_4 of this compound is called a *basic*

radical, and this means that it consists of a group of atoms which is very hard to separate and which reacts with other substances as if it were a single atom. Now, curiously enough, the radical NH_4 , although it is formed of two gases, reacts directly with acids precisely like the alkali metals in that it produces a series of salts. Not only this but like many of the metals, it forms an alloy with mercury, *i.e.*, an amalgam, and this has a lustrous metallic appearance.

In 1808 Davy isolated sodium, potassium and some of the other alkali metals from their oxides and Seebeck produced an ammonium amalgam. Berzelius and Pontain believed that ammonia, although it is a gas, must be an oxide like soda and potash and that, it follows, one of its constituents must be a metal. Davy was of a like opinion and to this supposed metal he gave the name *ammonium*. Ammonium is, then, a pseudo-hypothetical metal since the radical NH_4 acts like an alkali metal.

The Hypothetical Metal Junoium.—In 1811 Thompson obtained a substance from the mineral *allanite* which he believed to be a new metal. To this he gave the name *junoium* after Juno, the Roman goddess who was the consort of Jupiter. Later on Scheerer, and then Thompson himself, showed that his conclusion was at fault and due to an error in his analysis.

The Hypothetical Metal Vestium or Sirium.—In 1818 Berzelius announced the discovery of a new metal which he named *vestium* after *Vesta* who in the ancient Roman religion was the goddess of the hearth and its fire. The substitute name of *sirium* came from

that of *Sirius*, a star of the first magnitude in the constellation of *Canis Major*. This metal which has two names has never been verified and it is therefore now considered to be more or less mythical.

The Hypothetical Metal Donarium.—In 1851 Bergman obtained the rare earth thoria from the mineral *oranzite* and he announced that it contained a new metal; this he named *donarium* from the Latin word *donarium* which means a *useful gift*. It was later shown by Berlin, Damon and Delafontaine that the supposed new metal was formed of a mixture of thorium, uranium and lead.

The Hypothetical Metal Wasmium.—In 1862 Bohr claimed to have discovered a new metal in the minerals gadolinite and orthite, which he named *wasmium* after Wasmann, a friend of his. Then Delafontaine, Stevens and Papp said he was in error and that his supposed new metal was simply impure cerium. Nickles claimed it was a mixture of yttria, terbia and didymia and, finally, Bohr himself identified it with thoria.

The Hypothetical Metals Mosandrium, Phillipium, Decipium and X.—The discovery of four hypothetical metals was announced in 1878. The first of these was made by Smith who obtained the supposed new metal from the mineral samarskite; this he named *mosandrium* after the chemist Mosander of Stockholm. It was later shown to be a mixture, the chief constituent of which was the rare earth yttria.

The second supposed new metal was the alleged discovery by Delafontaine who found it in the rare earth yttria. He gave it the Neo-Latin name of *phillipium*

which means *invective* because he probably had need to use harsh and bitter words before he had obtained it and he certainly was justified in using it after he obtained it, for it proved to be a mixture of yttria and terbia.

The third of the supposed new metals to be found was due to Delafontaine's researches. He described a new oxide he had obtained from the mineral samarskite and this he named *decepia*. He got this name from the Latin *decipere* which means *to deceive* and, it follows, that the constituent metal was called *decipium*. Later on de Boisbaudran found the new oxide to be identical with impure didymia which he separated from samarskite. So in any event *decipium* lived up nobly and well to its cognomen.

The discovery of the fourth and last of the supposed new metals which was announced in 1878 was made by Soret who separated an oxide from the rare earth erbia, the constituent metal of which he designated by the letter *X*. It was afterward shown that *X* was identical with holmium.

The Hypothetical Metals $Y\alpha$ and $Y\beta$.—In 1880 de Marignac believed he had discovered two new metals and to the first of these, which he found in the mineral samarskite, he gave the provisional appellation of $Y\alpha$ and the second, which he obtained from gadolinium, the appellation of $Y\beta$. The Roman letter *Y* in both cases indicates their unknown nature while the Greek lower case letter α indicates that it was the first to be found by him and that of β indicates that it was the second. It mattered not at all which was first and which was

last for later on it was shown that $Y\alpha$ was identical with that of gadolinium and that $Y\beta$ was identical with samarium.

The Hypothetical Metals Columbium and Rogerium.—In 1884 Smith announced that he had discovered two new metals in samarskite. The first of these he called *columbium*, but this must not be confounded with the *columbium* that was discovered by Hatchett in 1801 and rediscovered in 1844 by Rose, who renamed it *niobium*. The second of the metals Smith named *rogerium* in honor of William B. Rogers, an American geologist, for whom the mineral *rogersite*, which is an alteration product of samarskite, was also named. Both columbium and rogerium proved to be mixtures of the rare earths instead of elemental metals.

The Hypothetical Metals $Z\alpha$, $Z\beta$, $Z\gamma$, Z and Si .—The years of 1885 and 1886 were fruitful ones as far as the discovery of hypothetical metals was concerned. In 1885 de Boisbaudran reported the discovery of two new metals in the rare earth terbia and to one of these he gave the provisional appellation of $Z\alpha$, the Roman Z standing for the unknown nature of the metal and the Greek letter *alpha*, which is equivalent to our *a*, meaning *the first*. To the other supposed metal he gave the appellation of $Z\beta$, the little Greek letter being *beta*, which is the equivalent of our *b* and, therefore, meaning *the second*.

Then in 1886 he announced the discovery of two more metals in terbia and to the first of these he gave the appellation of $Z\gamma$, the little letter being *gamma* which is the equivalent of our *g* but it is the third

letter of the Greek alphabet. The second supposed metal he designated simply by the letter *Z*.

Now *Z α* and *Z γ* proved to have been the previously discovered rare earth metal dysprosium, while *Z β* and *Z* were found to be the previously discovered terbium. Also in 1886 Demarçay announced the discovery of a new metal in the rare earth samaria and he gave it the appellation of *Si* and this later on turned out to be a mixture of the rare earths.

The Hypothetical Metals Austrium and Russium.—In 1886 Linnermann announced the discovery of a new metal which he had found in the mineral orthite and this he named *austrium* after his native country Austria. It proved, however, not to be a new metal but simply impure gallium. Then in 1887 Chrustchoff reported the find of a new metal which he had discovered in the mineral monazite. Being a Russian it was but natural that he should name it *russium*. Like many of the other hypothetical metals, his turned out to be a mixture of the rare earths.

The Hypothetical Metals *Z ϵ* and *Z ξ* .—In 1892 the prolific chemist de Boisbaudran announced the find of two more new metals in the rare earth samaria and he gave these the provisional appellations of *Z ϵ* , the little letter being the Greek *epsilon* which is the equivalent of our *e*, and *Z ξ* , the little letter being *xi* which is the equivalent of our *x*. These supposed new metals suffered the same fate as his 1885-1886 *Z* series for they were both found in due time to be identical with europium.

The Hypothetical Metal Lucinium.—In 1896 Barriere found what he thought was a new metal in

yttria and to which he gave the name of *lucinium*, a Neo-Latinized word that he derived from *lucis* which in turn came from *lux* meaning *light*. He so named it because it was used in the incandescent light of the Auer system. Lucinium, however, was destined to share the fate of many another hypothetical metal, for later on Crookes showed it to be an impure mixture composed chiefly of yttrium.

The Hypothetical Metals Kosmium and Neo-Kosmium.—In 1896 Kosmann put forth the claim to having discovered two new metals in the overworked rare earth yttria and to the end that his name might forever go thundering down the corridors of scientific achievement, he called one of them *Kosmium* and the other *neo-Kosmium*. These two purely mythical metals were patented for the purpose of making gas mantles, but, alas and alackaday, his two alleged metals were soon shown to be, simply, mixtures whose chief constituents were yttria.

The Hypothetical Metals Damarium and Glaucodymium.—In 1896 a supposed metal was found by Laner and Autsch in the mineral monazite and to it they gave the name *damarium*.¹ Whether or not it is an element has not yet been decided. In the next year another new metal was announced by Chrustchoff and this he found in the rare earth didymia. He named it *glaucodymium* from the Greek word *glaukos* which means *gray* and *didymos* meaning *twin*. The metal has not yet been verified.

¹ The origin of this name is uncertain. It may have been derived from *damaa*, which in Hottentot means *vanquished*, and from this, in turn, came *Damara*, meaning a native of Damara-land, a country in Southwest Africa.

The Hypothetical Metal Monium or Victorium.—

In 1898 Crookes announced the discovery of a new metal which he had found in the yttria earths and to it he gave the provisional name of *monium* from the Greek word *monios* which means *alone*, because the position of its spectrum line stood apart from the others. He later changed the name of it to *victorium* in honor of Queen Victoria. He calculated its atomic weight to be in the neighborhood of 117.0 and then Urbain upset the whole thing, metal and all, by showing that the spectrum and atomic weight of 58 parts of yttria and 226 parts of gadolinium were exactly the same as that of victorium and, hence, instead of being a new metal it was simply a mixture of these two rare earths.

The Hypothetical Metals Γ, Δ .—In 1900 four new metals were announced by Demarçay, and the first of these he indicated by the Greek capital letter Γ , which is *gamma* and equivalent to our capital letter *G*; the second by Δ , *delta* the equivalent to our letter *D*; the third Ω , *omega* the equivalent to our letter *O*; and the fourth and last θ , *theta*, and equivalent to our sound of *th*. The first two of these supposed new metals he obtained from the rare earth terbia, the Γ metal which was presently proved to be terbium, and the Δ metal which was proved to be dysprosium. The latter two supposed new metals he obtained from yttria and these have yet to be verified.

The Hypothetical Metal Euxenium.—In 1900 Hoffmann and Prandtl announced the discovery of a new metal which they called *euxenium* from the mineral *euxenite* in which they found it; this latter name

was derived from the Greek word *euxenos*² which means *good friend*, and the mineral was so named because it contains a number of rare earth metals. Hauser and Wirth failed to find any indication of the existence of the new metal in the mineral and neither has any been found since then, hence it follows it must be classed as one of the mythical hypothetical metals.

The Hypothetical Metals Berzelium and Carolinium.—In 1904 Baskerville added two more new metals to the hypothetical list, both of which he found in the mineral thorite. He named the first one *berzelium* in honor of the chemist Berzelius, and the second one *carolinium* after Carolina where Baskerville was born. Both of these supposed new metals were reported as being radioactive but neither of them have to date been verified.

The Hypothetical Metals Ionium and Incognitium.—In 1905 Crookes found characteristic lines in the ultra-violet end of the spectrum of the rare earth terbia and he believed that these were caused by the presence of two new metals which he named *ionium*³ and *incognitium*. The former was so called from the Greek god *Ion* who was the son of Apollo, while the second was derived from the Latin word *incognitus* which means *unknown*. Some time later Urbain found that the spectrum of varying mixtures of the sulphates of gadolinium and terbium gave lines which were iden-

² This came from the Greek roots *eu* which means *good* and *zenos* meaning *a friend*.

³ This is not the same element as the *ionium* discovered by Boltwood in 1907 in the uranium series and which is *radium emanation*.

tical with those obtained by Crookes from his ionium and incognitium.

The Hypothetical Metals Aldebarium and Cassiopeium.—In 1898 von Welsbach showed that ytterbia could be separated into two new metals and these he named *aldebarium* after Aldebaran, a star of the first magnitude in the constellation of *Taurus*, and *cassiopeium* after the northern constellation *Cassiopeia*. A year before von Welsbach announced his discovery, Urbain had found two metals in ytterbia and one of these he named *neo-ytterbium* which is now known as *ytterbium*, and the other *lutecium*, and as these were identical with aldebarium and cassiopeium Urbain was accounted to be the discoverer of the new metals and so the names he gave them have been retained.

The Hypothetical Metal E.—In 1910 Exner and Haschek announced that they had discovered in terbia a new metal which they provisionally designated by the letter *E*. It was, however, later proved to be a mixture of the rare earths.

The Hypothetical Metal Celtium.—In 1911 Urbain reported the discovery of a new metal in the mineral gadolinite and this he named *celtium*. This Neo-Latin name was derived from *Celtæ* which was the name applied by the ancient Romans to the Gauls. It was assumed to be a radioactive metal and that its rate of disintegration was about four times as fast as that of lutecium. Later on it was shown to be identical with that of the rare metal lutecium.

The Hypothetical Metals Tb1, Tb2 and Tb3.—In 1912 von Welsbach believed he had discovered three new metals in the rare earth terbia and provisionally

designated them *Tb1*, *Tb2* and *Tb3* respectively, the *Tb* being the symbol for the metal terbium. These metals have remained unconfirmed up to the present time.

The Hypothetical Metals Denebium and Dublium.—In 1916 Eber reported that he had found two new metals in the rare earth ytterbia. He named the first one *denebium*, after *Deneb*, a fixed star in any one of several constellations, and the second *dublium*, after *Duble*, a star of the second magnitude in the constellation of *Ursa Major*, or the Big Dipper as it is commonly called. The existence of these metals has thus far not been verified.

The Hypothetical Metals Eurasamarium and Welsium.—In 1917 Eber announced that he had discovered another new metal and this one he found in the mineral samarskite. He called it *eurasmarium* because its position in the periodic system was between that of europium and samarium. Finally, in 1920, Eber reported the discovery of still another new metal in the rare earth terbia, which lay between terbium and dysprosium. This metal he named *welsium* in honor of the chemist von Welsbach. Neither of these metals has been verified up to the present time.

CHAPTER X

THE OLDER ALLOYS

WE get the word *alloy* from the Latin stem *alligare* which means *to bind* and, it follows, this came from the roots *ad* which means *to* and *ligare* meaning *bind*. Now an alloy in its simplest sense is produced when two or more metals are melted and mixed together as, for example, in the combination of copper and tin, the alloy of which we call *bronze*. An alloy also results when one or more of the nonmetals are mixed with a melted metal or metals, for instance, carbon with melted iron.

Alloys are of two general kinds, those (1) in which the metals and nonmetals forming them are *mechanically mixed*, and (2) in which they are *chemically combined*. An alloy of the first kind has a *heterogeneous* structure and its different components can be easily seen by polishing the surface of the sample, then etching it with acid and examining it under the microscope. Thus if you so treat and examine gray cast iron you will be easily able to distinguish the carbon content from the iron.

An alloy of the second kind has a *homogeneous* structure, that is, its components are so thoroughly combined that they cannot be detected with a microscope. *Hard steel*, which is an alloy of about 1 per cent of carbon with iron, is of this kind, as are various

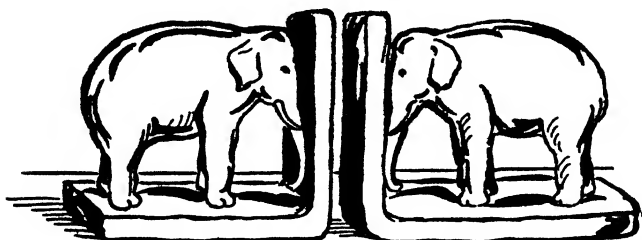
other alloys, such as copper and manganese and copper and magnesium.

The alloys of the various metals and nonmetals take on physical properties that are, in general, very different from the components of which they are formed. As an illustration, alloys have a lower melting point than their component metals and they are usually considerably harder than the components which compose them. Further, certain alloys exhibit some very remarkable properties which have to do with their expansion, electric resistance, magnetic susceptibility, etc., and these will be described in connection with the various kinds as we take them up.

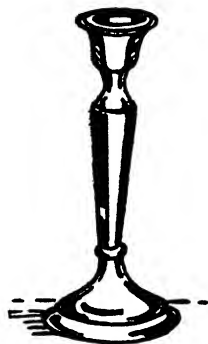
The Alloys of Copper.—The oldest known alloys are those in which the chief component is copper, since this was the first metal that was worked by man. By alloying copper with some of the other metals its properties can be greatly changed and, it follows, its uses can be widely extended. The chief alloys of copper are known as (1) bronze, and (2) brass. Now the difference between bronze and brass is that the former consists of copper alloyed with tin, with occasionally small proportions of other metals and nonmetals added to it, while the latter consists of copper alloyed with zinc.

The Alloy Called Bronze.—The name *bronze* may have been coined in early Roman days from the city of Brundizium which is now known as Brindisi, Italy. Bronze was the earliest known alloy and was used for making tools and weapons, long before primitive man knew of iron. Bronze is a hard, brittle and sonorous alloy, its properties in these respects depending on the

relative proportions of its component metals. Because it was easily melted and tough, it was used for castings until the eighteenth century when the method of casting



A- Bronze



B- Brass

FIG. 31.—USEFUL HOUSEHOLD OBJECTS MADE OF BRONZE AND BRASS ALLOYS

iron was discovered. A bronze casting is shown at *A* in *Figure 31*.

The Alloy Called Brass.—The name brass was derived from the Middle English *bras* and this from the Anglo-Saxon *braes*, and, it follows, this alloy must be of comparatively recent origin. The various brass alloys

FORMULAS FOR BRONZE

<i>Kind</i>	<i>Copper, per cent</i>	<i>Tin, per cent</i>	<i>Zinc, per cent</i>	<i>Other Metals, per cent</i>
Church bell metal ..	78	22		
Bronze for medals ..	93.0	7.0		
Statuary bronze	90.0	3.0	2.0	
Phosphor bronze ...	92.0	8.0		
Silicon bronze	90.0	5.0		
Gun metal	91.0	9.0		
Coinage bronze	95.0	4.0	1.0	
Britannia metal.....	45.5	1.5		Lead 50.0
Speculum metal ¹ ...	66.6	33.4		

¹ Used for reflectors of telescopes.

FORMULAS FOR BRASS

<i>Kind</i>	<i>Copper, per cent</i>	<i>Zinc, per cent</i>	<i>Tin, per cent</i>	<i>Other Metals, per cent</i>
Common brass	84.7	5.3	10.0	
Tough brass	55.0	44.5	0.5	
Yellow brass	66.66	33.33		
White brass	10.0	80.0	10.0	
Mosaic gold ¹	67.0	33.0		
Pinchbeck ²	85 to 90	15 to 10		
Gilding metal	93	7 to 10		
Red brass	82	18 to 10		
Dutch metal ³	80	20 to 10		
Muntz metal ⁴	58.96	39.77 to 10		
Tombac ⁵	91		0.46	Lead .41 Iron .13

¹ This is an imitation gold the effect of which is heightened by means of a lacquer or the use of acids.

² From the name of the inventor. Used to imitate gold in making cheap jewelry.

³ Rolled or beaten in thin sheets and used in Holland to ornament paper and toys.

⁴ Made originally by G. F. Muntz in 1832 for ship's sheathing and like purposes.

⁵ Used for making cheap jewelry, gilding, etc.

range all the way from white to yellow in color, depending on the kinds and proportions of their alloying metals; thus a brass which contains a large per cent of tin is white while that which contains a large per cent of zinc is yellow. Brass is very malleable, ductile and easily machined, but these and other properties of it depend, of course, very largely on its composition.

The Alloys of Iron.—Pure iron is too soft to be used for practical purposes. *Piano wire* is the purest that is used and this contains only about 0.3 per cent of foreign substances. *Cast iron*, which is made in the blast furnace, contains from 2 to 5 per cent of carbon and a like percentage of silicon along with small proportions of manganese, sulphur and phosphorus. Cast iron melts easily, is very brittle and while it can be tempered it cannot be welded or forged. The two chief grades of cast iron are called (1) *foundry iron* and (2) *forge iron*; the latter kind contains a large percentage of combined carbon and is used in making *wrought iron*.

What is known as the *weld metals* are made of iron that has not been thoroughly melted and these, in consequence, contain *slag*. These iron alloys are known as (a) *weld* or *wrought iron* and this has about 3 per cent of slag in it, and (b) *weld*, *puddled*, *semi-steel*, *blister*, or *cement steel*, as it is variously called, and this has from 2 to 3 per cent of slag in it.

The *ingot metals* are those iron alloys that are made by thoroughly melting and, hence, they contain no slag. There are three general kinds of these alloys and they are known as (a) *Bessemer steel*, (b) *open-hearth steel* and (c) *ingot steel*. All of the above iron alloys have

a carbon content ranging from 0.1 to 3.0 per cent and the first two are called *low*, *soft* or *mild steel*, while the third, which has from 0.3 to 2.0 per cent of carbon in it, is known as *hard steel*.

When small amounts of various metals such as aluminium, manganese, silicon and titanium are added to iron in order to purify it, they are called *scavengers* or *medicines*, for they combine chemically with the impurities in it and form slag so that they make up a part of the alloys themselves. When larger amounts of the various metals are added to iron, what are known as *steel alloys* result as these mix or combine with the iron and so form constituent parts of them. The various new steel alloys will be described in the next chapter.

FORMULAS FOR IRON ALLOYS (FERRO-ALLOYS)

Ferro-chromium contains about 67 per cent chromium, 33 per cent iron.

Ferro-manganese contains 80 per cent manganese, $6\frac{3}{4}$ per cent carbon, $13\frac{1}{4}$ per cent iron.

Ferro-silicon alloys are of several grades and these contain 50, 75, 80 and 95 per cent of silicon; carbon about 0.5 per cent, phosphorus and sulphur less than 0.10 per cent and the rest iron.

Ferro-tungstate contains 60 to 85 per cent of tungsten and the rest iron.

Ferro-vanadium contains 35 per cent vanadium and 65 per cent iron.

The Alloys of Tin.—*The Old Alloy Pewter.*—This alloy was probably made by the Chaldeans, the Egyptians, the Greeks and the Romans, but the name we use for it comes from the Middle English word *pewtyr*. Now there are various formulas for making pewter but

the chief component of all of them is tin. (1) The finest kind of pewter consists of 90 per cent of tin and 10 per cent of copper. (2) The inferior kinds are made of 75 per cent of tin and 25 per cent of lead. Small amounts of antimony and bismuth are also often added to make the alloy expand if it is to be cast. (See *Figure 32.*)

What Babbitt Metal Is.—This metal is an *anti-friction alloy*, and it is made in many varying propor-



FIG. 32.—OBJECTS MADE OF THE OLD ALLOY CALLED PEWTER

tions. One of the standard formulas for Babbitt metal is 88.9 per cent of tin, 3.7 per cent of copper and 7.4 per cent of antimony. Another formula calls for 19 per cent of tin, 6.9 per cent of zinc, 5 per cent of lead, 3 per cent of antimony, 4 per cent of arsenic, and the rest copper. This latter formula gives an alloy that is, in general, quite soft but which contains hard particles. When used as a bearing the latter bear most of the pressure of the shaft, yet as the alloy wears down the hard particles are forced into the softer metal and in this way a hard and smooth surface is always provided.

Type and Stereotype Metals.—These alloys have a low melting point and, in contrast to nearly all other metals and alloys, they expand on cooling. One of the formulas for type metal is 20 per cent of tin, 60 per cent of lead and 20 per cent of antimony. A formula for stereotype metal is 10 per cent of tin, 70 per cent of lead, 18 per cent of antimony and 2 per cent of copper. A little nickel is often added to these alloys to make them hard and, it follows, more durable.

Kinds of Solders.—We get the word *solder* from Latin *solidare* which means *to make solid*. Now a solder is an alloy that is used to join metal surfaces together. To make the solder flow freely and to hold tightly a *flux* such as resin, borax or zinc chloride must be used to keep clean the surfaces of the metal to be soldered.

There are two chief kinds of solders and these are known as (1) *soft solders* which melt at a low temperature, and (2) *hard solders* which require a red heat to melt them. These latter solders are used for brazing brass and soldering gold, silver and other metals that have a comparatively high melting point and these will be described presently.

FORMULAS FOR SOFT SOLDERS

<i>Kind</i>	<i>Tin, per cent</i>	<i>Lead, per cent</i>
Tinner's solder	50	50
Plumber's solder	33	67

The Alloys of Nickel.—*The Alloy Called German Silver.*—This alloy is not German, neither is there any silver in it. It has, however, a white silvery color, does

not oxidize when exposed to the air, is hard and tough, and malleable and ductile. It is formed of 25 per cent each of nickel and zinc and 50 per cent of copper.

The Alloy for Nickel Coinage.—The properties of alloys, as I have previously mentioned, are usually very different from those of the metals they are made of. Thus, in the nickel coinage alloy, although the greater percentage of it is copper, it yet holds the color of the nickel that is in it. The alloy of which the five-cent piece, which we call the *nickel*, is made contains 25 per cent nickel and 75 per cent copper. *Monel metal* and



FIG. 33.—MONEL METAL, A NATURAL ALLOY

The well-dressed locomotive wears jacket bands and cylinder casings of silvery monel metal.

nickel steel are newer alloys of nickel and these will be described in the next chapter. (See *Figure 33*.)

The Alloys of Gold.—Pure gold is much too soft to be used for jewelry and coinage and so it is generally hardened by alloying it with a little silver or copper. The gold-copper alloys are the most important as they are used both for jewelry and coinage. The standard gold-copper alloy consists, roughly, of 90 per cent gold and 10 per cent copper, and this makes a very malleable and ductile alloy and one that is extremely suitable for this purpose.

Coinage and Jewelry Gold-Copper Alloys.—As I explained in the chapter on the *noble metals* a *carat* is the unit of weight for gold and the more precious metals

and it is used for estimating the fineness of them. Thus gold that is absolutely pure is 24 carats fine and as the percentage of other metal that is used with it is increased, it follows that the fineness of the gold decreases, as the following table clearly shows:

STANDARD GOLD-COPPER ALLOYS

<i>Fineness</i>	<i>Gold, per cent</i>	<i>Copper, per cent</i>
22 carats fine	91.6	8.4
18 carats fine	75.0	25.0
15 carats fine	62.5	37.5
9 carats fine	37.5	62.5

The first of these alloys, namely the 22 carats fine, is too soft for jewelry in general but is often used for wedding rings and mountings of rings which hold the precious stones and which have to be very ductile. The 18 and 15 carat alloys are those that are usually employed for high grade jewelry, and the 9 carat alloy is used where the jeweler is honest but not too honest.

A Blue Gold Alloy.—This alloy which is called *blue gold* is made of 75 per cent gold and 25 per cent iron.

A White Gold Alloy.—This is made by melting together from 90 to 80 per cent of gold and 10 to 20 per cent of palladium.

A Hard Gold Solder.—For this solder use 75 per cent 18 carat gold, 15 per cent silver and 10 per cent copper. For a softer hard gold solder and one that will melt at a lower temperature use 11.94 per cent gold, 54.74 per cent silver, 28.17 per cent copper and 5.01 per cent zinc.

The Alloys of Silver.—*Silver-Copper Alloys.*—A silver-copper alloy for either silver plate or for coinage

should contain as much as 90 per cent of silver and certainly not less than 80 per cent of silver. What we call *sterling silver* is an alloy of 92.5 per cent silver and 7.5 per cent copper; this is the proportion that has been legalized as the standard by Great Britain and it is the kind that is *hall-marked*.¹ Where the alloy contains less than 90 per cent silver it cannot be hall-marked. This lower grade and on down to that which contains as little as 60 per cent silver is, however, often used for jewelry.

Silver-Platinum Alloys.—These alloys are chiefly used by dentists for filling teeth and for this purpose they are better than silver-copper alloys as they do not blacken as easily and are much more durable. The two chief kinds are those which contain (1) 67 per cent silver and 33 per cent platinum, and (2) 75 per cent silver and 25 per cent platinum.

Silver-Tin Alloys.—These alloys are used for making amalgams with mercury which are used by dentists for filling teeth. The chief silver-tin alloys are made of 40 to 60 per cent silver and 60 to 40 per cent tin.

Silver-Cadmium Alloy.—This alloy is used in the place of pure silver for the anode in electroplating because it does not oxidize so easily. It is formed of from 80 to 99.5 per cent silver and 20 to 0.5 per cent cadmium.

Hard Silver Solders.—Hard solder for silver is formed of silver, copper and zinc. The more silver a

¹ The term *hall mark* is the official mark of the Goldsmiths' Company of London, that is stamped on gold and silver articles to attest their purity.

solder has in it, the harder it is and the higher its melting point.

FORMULAS FOR SILVER SOLDERS

	Silver, per cent	Copper, per cent	Zinc, per cent
Common	62	30.5	7.5
Easy	70	22.5	7.5
Hard	80	17.5	2.5

The Alloys of Platinum.—Since platinum is much more expensive than gold it is not used to any great extent for alloys though some jewelry and considerable chemical apparatus is made of it.

FORMULAS FOR PLATINUM ALLOYS

Cooper's gold contains 19 per cent platinum and 81 per cent copper. It has the color of 18 carat gold, is malleable and ductile and does not corrode.

Platinum silver alloys: (1) contain 33 per cent platinum and 67 per cent silver; (2) contain 25 per cent platinum and 75 per cent silver. These are known as *dental alloys* but are used to only a small extent.

Standard electrical resistance alloy contains 33 per cent platinum and 67 per cent silver.

Platinum soldering alloy contains 27 per cent platinum and 73 per cent silver.

Platinum-iridium alloy contains 90 per cent platinum and 10 per cent iridium. It is used for one of the wires in *thermocouples* and this, in turn, is used for the measurement of high temperatures, the other wire being pure platinum. It is also adopted by the Bureau of Standards for standard weights and measures.

CHAPTER XI

THE NEWER ALLOYS

THE art and science of metallurgy has advanced by leaps and bounds during the last quarter of a century, but in no branch of it has the progress been more marked than in that which has to do with the making of new and useful alloys. The following are the chief outstanding ones.

The Newer Alloys of Iron and Steel.—*Duriron and Tantiron.*—These alloys are *rustproof* and are not attacked by hot or cold, dilute or concentrated acetic, nitric or sulphuric acids. *Duriron* is formed of 14 to 15 per cent silicon, 2 to 2.5 per cent manganese, 0.75 to 1.25 per cent carbon, 0.05 to 1.0 per cent phosphorus, 0.05 to 0.15 per cent sulphur and enough iron to make up 100 per cent. *Tantiron* consists of 83.50 per cent iron, 15.0 per cent silicon and 1.10 per cent carbon.

The Alloy Permalloy.—The *permeability* of a metal or other substance is the ease with which it will conduct magnetic lines of force. Thus iron has a permeability that is several hundred times greater than that of air. Now the Western Electric Company developed an alloy which they named *permalloy*, and this has an initial permeability which is about 30 times greater than that of soft iron; it consists of 78 per cent nickel and 22 per cent iron.

The Ferro-alloys.—These are not true alloys, for very small amounts of the different metals are added to melted steel to make sounder and, it follows, better castings. These metals do not mix with the steel but they combine with the gases and other elements and so purify it.

Ferro-aluminum alloy is made simply by adding a small amount of aluminum to the melted steel. The aluminum combines with the oxygen of the steel, and this is itself combined with the carbon in it; the reaction forms aluminum oxide and this passes into the slag.

Ferro-titanium alloy is constituted of 10 to 15 per cent of titanium added to melted steel. This combines with both the oxygen and nitrogen there is in it, when these compounds pass into the slag. *Ferro-vanadium alloy* is formed by adding 0.10 to 0.15 per cent of vanadium to the melted steel and this not only removes the oxygen and nitrogen from the steel but at the same time greatly strengthens it.

Nickel-Steel Alloy.—When pure steel is alloyed with 2 to 4 per cent of nickel it is exceedingly hard, resists corrosion remarkably well and has a very high limit of elasticity. It is, therefore, used for armor plate, propeller shafts, wire cables, grids, etc. (See *Figure 34.*)

The Alloy Invar.—This alloy gets its name from the word *invariable* because its *coefficient of expansion*¹ is exceptionally small. Thus the actual linear expansion

¹ This term means the ratio of the increase of *length*, of *area* or of *volume* of a body for a given rise in temperature (usually from 0 to 1 degree centigrade) to the original length, area or volume respectively.

of the pendulum of a grandfather's clock, which is approximately 39 inches long, will, when its temperature is raised 1 degree centigrade, or 1.8 degree Fahrenheit, become only two one-hundred thousandths (0.000002) part of an inch longer. Invar consists of 36 per cent nickel and 64 per cent steel.

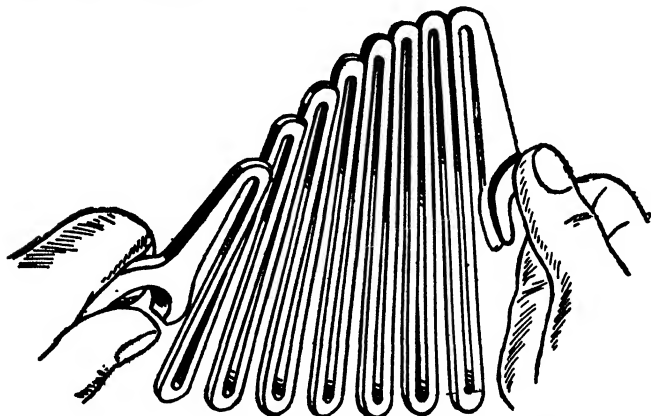


FIG. 34.—A NICKEL CAST-IRON RESISTANCE GRID
It is so flexible it can almost be tied in a knot.

Manganese Steel.—This alloy may vary in its proportion from 7 to 20 per cent manganese and from 93 to 98 per cent steel. It is a very hard and tough alloy and even when it is heated by frictional contact with other metals it does not lose its temper. It is used for burglar-proof safes, rock-crushers and railroad frogs and crossings.

Chrome or Chromium Steel.—(1) When 3 per cent of chromium is added to steel it makes a very fine grained and exceedingly hard alloy. (2) When 60 per cent of chromium, 36 per cent of steel that has no carbon in it, and 4 per cent of molybdenum are melted

together the resulting alloy is practically acid-resisting and one that is scarcely affected by even boiling hot acids.

(3) To make a *stainless steel alloy*, that is, one which does not tarnish when it comes in contact with food-stuffs, you need only to melt 12 to 14 per cent of chromium with 86 to 88 per cent of pure steel. Chromium when used either by itself or in sufficient quantities in alloys, is extremely resistant to corrosion.

Chrome-Vanadium Steel.—When 1 per cent of chromium and 0.15 per cent of vanadium are added to pure steel an alloy of such remarkable tensile strength results that it can be bent double when cold and still not break. It likewise opposes changes of stress and torsion with great resistance and these are the sufficient reasons why it is used for shafts, frames and axles of motor cars.

Tungsten or High Speed Steel.—Obviously this alloy is called *tungsten steel* because it contains both tungsten and steel. Why it is called *high speed steel* is just as obvious when you know the reason, and that is when a tool is made of it for cutting metals the latter can move at a speed high enough so that although the friction heats the tool red-hot it will not lose its temper. Tungsten steel or high speed steel contains from 10 to 20 per cent tungsten, 3 to 5 per cent chromium and the remainder steel.

The Newer Bronze Alloys.—*Aluminum Bronze or Aluminum Gold*.—This alloy is the finest bronze that has yet been made but its high cost has prevented it from being very widely used in the arts except for making jewelry. It has a beautiful golden color while

its mechanical and electrical properties surpass that of any other bronze, being at once light, strong, and resistant to oxygen and other chemical reactions. This alloy consists simply of 5 to 12 per cent aluminum with 95 to 98 per cent copper. The alloy when powdered and mixed with oil makes a very fine silvery-white paint.

Vanadium Bronze.—When copper and zinc are melted together and a very small amount of vanadium is added to them they form a bronze that is remarkably hard and tough. The formula for making vanadium bronze is to use 61 per cent copper, 38.5 per cent zinc and 0.5 per cent vanadium.

Manganese Bronze.—This is a bronze that contains a small amount of manganese and this makes it very hard and tough. There are different formulas for manganese bronze and some of these contain zinc and some tin. The bronze containing the former metal is made of 88.00 per cent copper, 8.5 per cent zinc, 1.5 per cent manganese, the rest of it consisting of small amounts of iron, lead and phosphorus. The bronze containing tin is made of 88.00 per cent copper, 10.00 per cent tin and 2.00 per cent manganese.

Tungsten Bronze.—The properties of this alloy are in some respects quite like those of manganese bronze which I have just described. It is a very simple alloy, being made of 90.00 per cent copper and 10.00 per cent tungsten.

Phosphor Bronze.—This is a very hard, highly elastic and exceedingly tough alloy and these properties are due to the introduction of a small amount of phosphorus. The kind of phosphor bronze that is used for

radio aerial wires contains 98.75 per cent copper, 1.2 per cent tin and 0.05 per cent phosphorus.

Silicon Bronze.—This is also a very strong bronze that has a high tensile strength and is practically non-corrosive. For these reasons it is largely used for aerial wires. It is made of 97.12 per cent copper, 1.12 per cent zinc, 1.14 per cent tin and 0.52 per cent silicon.

Manganin.—This alloy is formed of 84 per cent copper, 12 per cent manganese and 4 per cent nickel. Although it contains so large a percentage of copper, it has a high electric resistance, its conductivity being about 30 times less than that of copper. Wire made of this alloy is largely used in electrical instruments because its resistance does not change with ordinary changes of temperature.

The Newer Alloys of Aluminum.—*An Aluminum-Gallium Alloy.*—This is one of those scientific believe-it-or-not things. If you will hark back to *Chapter VI* you will remember that gallium is one of the rare earth metals, that while it is tough it can be cut with a knife, and that it has a very low melting point, namely 30 degrees centigrade, or 86 degrees Fahrenheit. If now you melt aluminum and gallium together they will form an alloy that will remain a liquid when it gets cold.

Aluminum-Zinc Alloy or Aluminum-Brass.—This is a simple alloy that is formed of 70 per cent of aluminum and 30 per cent of zinc. It is very light when compared with cast iron and very brittle² but sufficiently strong for casting small parts such as the frames of sewing machines.

² Any alloy that contains from 11 to 89 per cent aluminum is very brittle and highly crystalline.

Aluminum-Silver Alloy or Mock Silver.—This alloy has a beautiful silvery white color and there is sufficient copper and tin in it to give it enough weight so that it approximates that of silver and, hence, it is called *aluminum silver* or *mock silver*. It is formed of 84.29 per cent aluminum, 10.20 per cent tin, 5.50 per cent copper and 0.01 per cent phosphorus.

Aluminum Solder.—To solder aluminum you do not use a solder made of this metal but instead one that contains 65 per cent tin, 30 per cent zinc and 5 per cent bismuth.

*Duralumin.*³—This alloy, which is often called *dural* for short, gets its name from *durable* plus *aluminum*. It is largely used in the construction of aircraft frames for, while it is very light, its hardness and strength is almost equal to that of soft steel. Duralumin, which is a trade-mark name, is formed of 95.5 per cent aluminum, 3 per cent copper, 1 per cent manganese and 0.5 per cent magnesium.

*Duralium.*⁴—This alloy is formed of 93 to 95 per cent aluminum, 3.5 to 5.5 per cent copper and small amounts of magnesium manganese. It resists dilute acids and sea water and is used for making chemical apparatus such as retorts, etc.

Magnalium.—This alloy gets its name from *magnesium* plus *aluminum*. Now while aluminum is hard to work with hand tools or on a lathe, when it is alloyed with from 2 to 5 per cent of magnesium it forms an alloy that quite removes this difficulty.

³ Pronounced *du-ral'-u-min*.

⁴ Pronounced *du-ral'-e-um*.

Fusible or Eutectic Alloys.—The term *fusible* or *eutectic alloy* means one that has a very low melting point. We get the word *eutectic* from the ancient Greek *eutektos* which means *easily melted*. Fusible metals or alloys are used chiefly for making soft solders, taking impressions of coins, medals and the like, fillings for teeth, electric fuses, automatic sprinklers and safety plugs in boilers. Fusible alloys consist of bismuth and

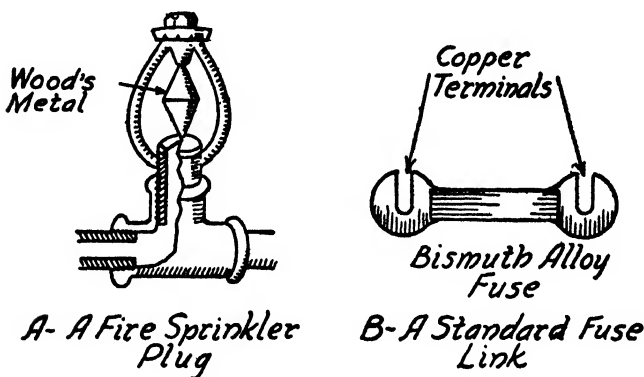


FIG. 35.—OBJECTS MADE OF FUSIBLE METAL

other metals that have low melting points and the resulting alloy, curiously enough, will melt at a much lower temperature than that at which any of its constituent metals will melt. (See *Figure 35*.)

Fusible alloys are made chiefly of three metals and these are bismuth, tin and lead; some of them, however, have a fourth metal in them and this is cadmium; and one of them a fifth metal which is mercury. By varying the proportions of these constituent metals an alloy can be formed that will melt at any temperature you want it to. The fusible alloys which follow are,

with the exception of the first, named after their inventors.

FORMULAS FOR FUSIBLE ALLOYS

<i>Alloy</i>	<i>Percentage Composition</i>				<i>Melting Point</i> ¹
	<i>Bismuth</i>	<i>Tin</i>	<i>Lead</i>	<i>Other Metal</i>	
Anatomical	53.5	19.0	17.3	mercury 10.5	140° F. or 60° C.
Wood	50	12.5	25	cadmium 12.5	159.8° F. or 71° C.
Rose	50	22.9	27.1		200.75° F. or 93.75° C.
Newton . . .	20	30	50		202.1° F. or 93.75° C.
Lipowitz . .	50	13	27	cadmium 10	140° F. or 60° C.
Lichtenberg	50	20	30		196.9° F. or 91.6° C.

¹ Water boils at 212°F., or 100°C.

Heusler's or Non-ferro-magnetic Alloys.—In 1903 Heusler made the remarkable discovery that certain metals which are only magnetic to an almost negligible degree become quite strongly magnetic when an alloy is made of them. This apparently shows that magnetism depends on the molecular structure of a metal rather than on its atomic arrangement.

The best of these magnetic alloys consists of 25 per cent manganese, 61 per cent copper and 14 per cent aluminum. The degree of magnetism shown by this alloy is about $\frac{1}{8}$ of that of pure soft iron. Magnetic alloys can also be formed of manganese and tin and these as well as those of copper can also have small quantities of antimony, arsenic, tin, bismuth and boron in them without affecting their magnetic properties.

The Cerium or Pyrophoric Alloys.—If you will hark back to the chapter on the *Rare Earth Metals*, you will remember that cerium gives forth sparks when

it is scratched with steel. Now that class of alloys which consists of cerium as the chief metal has the above fire-generating property and to it has been given the name of *pyrophoric alloys*.

The word *pyrophoric* comes from the Greek roots *pyro* which means fire and *phoros*, to bear, and means a substance that will ignite spontaneously when exposed to the air. The cerium alloys do not quite fulfill this condition because they have to be struck with a piece

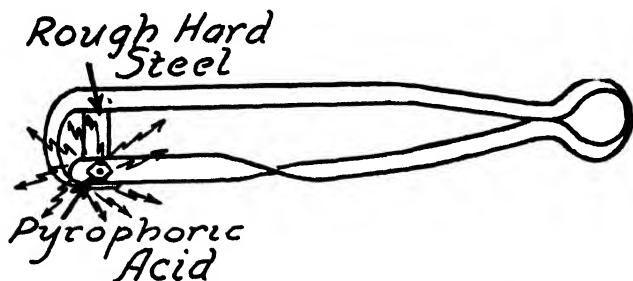


FIG. 36.—A PYROPHORIC GAS LIGHTER

of steel first, but for the purpose this is considered near enough.

The chief pyrophoric alloy is ferro-cerium and this contains about 70 per cent cerium and 30 per cent iron. Sometimes a little copper is added to harden it and a little bismuth is put in to make it more fusible. A more highly pyrophoric alloy is made of 75 per cent cerium and 25 per cent platinum. (See *Figure 36*.)

Miscellaneous Alloys.—There are numerous alloys that contain a number of different metals, and are used for special purposes. You will find a few of the outstanding ones below.

The Alloy Constantan.—The name of this alloy is

derived from the word *constant* and this in turn from the Latin *constans*. It is used as one of the elements of the thermopile⁵ and also in some instruments as an electric resistance. The alloy constantan consists of 54.15 per cent copper, 43.70 per cent nickel, 0.435 per cent iron, 1.34 per cent cobalt, 0.0237 per cent sulphur, 0.0011 per cent phosphorus, 0.098 per cent silicon, and 0.14 per cent carbon.

Carboloy or Cobalt-tungsten Alloy.—This is an alloy formed of cobalt and tungsten carbide and is the hardest known alloy. It is so hard that it will scratch sapphire and it possesses the unique property of getting harder when it is heated. The exact proportions of the metals used have been kept a secret.

A Lead-magnesium Alloy.—When an alloy made of 95 per cent lead and 5 per cent magnesium is exposed to moist air it oxidizes very rapidly, swells up and then in a few hours falls to a black powder. This alloy decomposes water and liberates the hydrogen of it. It is especially active in this respect when the magnesium is increased to 30 per cent.

⁵ This is an apparatus formed of two or more different kinds of metals joined together and when the juncture is heated a current is set up.

CHAPTER XII

WHAT THE AMALGAMS ARE

MERCURY is the only metal we have that is normally a liquid at ordinary temperatures. Nearly all of the other metals will dissolve in it and while such a mixture is an alloy it is called an *amalgam*. We get this name from the Latin and Greek words *malagma* and this is derived from the root *malakos* which means *soft*.

Now amalgams are made in any one of a number of ways and these are (1) by bringing the mercury and the other metal into contact with each other; (2) by placing the mercury and the other metal together in dilute acids; (3) by heating the mercury and the other metal together; (4) by putting the mercury into a saturated solution formed of a salt of the other metal; (5) by making a solution formed of a salt of the mercury and putting the other metal in it, and, finally, (6) by electrolysis, that is by using a cathode of mercury, then making a solution of a salt of the other metal and passing an electric current through it when it (the other metal) will be deposited on and amalgamated with the mercury.¹

Amalgams of the Alkali Metals.—The alkali metals, *i.e.*, sodium, potassium, lithium, cesium and

¹ This is the process that Madame Curie used to obtain the metal radium from its salt, radium chloride. After the radium had formed an amalgam with the mercury she expelled the latter by distillation.

rubidium, easily dissolve in and amalgamate with mercury at room temperature, and still more easily when the mercury is heated. Sodium reacts with mercury so violently that when a piece is dropped into it so much heat is developed that it often explodes and is thrown out of the dish. Potassium also reacts violently with mercury but not as much so as does sodium, lithium, cesium and rubidium.

Amalgams of any of the above alkali metals can be made by direct contact with mercury, either when the latter is cold or heated. To do this you need only to rub the two metals together in a dry mortar that has a cover on it and then keep the resultant mass under a layer of petroleum until you want to use it. Sodium amalgam is chiefly used in helping along the making of other and more difficult amalgams, a very small amount of it aiding greatly to make the amalgamation take place more easily and quickly.

Amalgams of the Rare Earth Metals.—The chief metals of this group are calcium, strontium and barium. Amalgams of these metals can be made in various ways but they are not at all easy to make. One way is to make a 2 per cent solution of the chloride of whichever one of the above metals you want to use for the amalgam and then add a 1 per cent solution of sodium or potassium to it to help the good work along.

This done, put it in a test tube or a bottle with 98 per cent of mercury and stir them together. There will be a little gas given off and when this has stopped you can remove the amalgam; then dry it by pressing it between filter paper and to keep it put it in a bottle

of petroleum. These amalgams can also be made by electrolysis.

A Couple of Hypothetical Amalgams.—Ammonium Amalgam.—The properties of ammonium amalgam were given in the chapter on the *Hypothetical Metals*. Now while ammonium is a gas each of whose molecules is formed of 1 atom of nitrogen and 4 atoms of hydrogen (NH_4) it is miscible with mercury and it is the only known radical that will mix with it.² This amalgam is interesting because it tends to show that if ammonium could be isolated it would be a metal. Chemists of the present time, however, consider it to be not a true amalgam but a mixture of mercury and ammonium and that the two gases which form it penetrate into the mass of mercury and entangle its molecules and that it is this which gives it the appearance of a frothy amalgam.

Ammonium amalgam can be made in different ways but the one used by Seebeck in 1805 is as simple and as good as any of the others. He cut a cavity in a piece of ammonium carbonate, filled it with mercury and set it on a metal plate which was connected with the positive pole of a battery. As the ammonium carbonate was decomposed the ammonium passed into the mercury and caused the latter to swell up into a frothy mass which was about as thick as butter, and this he considered to be ammonium amalgam.

Hydrogen Amalgam.—In much the same way that ammonium amalgam is made so also can hydrogen amalgam be made. Lewis and Jackson, in 1906, deduced the existence of hydrogen amalgam from the

² Hydrogen alone is miscible with mercury.

behavior of the mercury cathode during the separation of hydrogen in electrolysis.

Amalgams of the Common Metals.—*Aluminum Amalgam.*—It is not at all an easy matter to make an aluminum amalgam but it can be done by either (1) melting the aluminum and adding it to the mercury in a gas which will not combine with them, or (2) by rubbing the mercury on the aluminum in a solution of potassium hydroxide.

Bismuth Amalgams.—Amalgams made of bismuth are very plastic but harden gradually. They are, therefore, used for filling out anatomical pieces and delicate molds. When bismuth is added to other amalgams it makes them more plastic and as other common metals are cheaper than bismuth they are often used with a small amount of the latter added to them.

Anatomical Amalgams.—(1) For this amalgam use 48 per cent bismuth, 3 per cent lead, 28 per cent tin and 9 per cent mercury. This amalgam melts at 77.5 degrees centigrade, or 170 degrees Fahrenheit, and becomes a solid mass at 60 degrees centigrade, or 140 degrees Fahrenheit. (2) When an amalgam is made of 90 per cent D'Arcets' alloy^a and 10 per cent mercury it melts at 53 degrees centigrade, or 125 degrees Fahrenheit, and at a lower temperature it has the consistency of paste.

Lipowitz' Amalgam.—This amalgam is extremely well suited for taking impressions of leaves and other delicate objects as they come out very sharp, have a white, silvery appearance and a nice glossy surface.

^a This alloy consists of 66½ per cent bismuth and 33½ per cent tin. It melts at 93 degrees centigrade, or 200 degrees Fahrenheit.

To make it add the mercury, which you have heated to about 100 degrees centigrade, or 212 degrees Fahrenheit, to 2 per cent of Lipowitz' alloy⁴ which is in the melted state. The amalgam must be removed from the fire as soon as the mercury is put into the melted alloy and stirred with an iron rod until it begins to get solid. It melts at about 62 degrees centigrade, or 140 degrees Fahrenheit.

Cadmium Amalgams.—Amalgams of cadmium are easy to make and they remain in a plastic condition for quite a long time and can be kneaded like putty. While they do not get solid, however, they become very hard and can then be filed, turned, or otherwise worked. They are silvery-white in color and do not oxidize in the air. Here are two formulas for making them: (1) 25.99 per cent cadmium and 74.01 per cent mercury, and (2) 21.75 per cent cadmium and 78.26 per cent mercury. The mercury must be heated to nearly its boiling point in a crucible and then put into it the cadmium in thin sheets.

Copper Amalgams.—When amalgams made of copper have stood for some time they become exceedingly hard and fine-grained and are malleable and ductile. When they are polished they look like gold and do not tarnish in air unless there is present hydrogen sulphide which turns them black. If the amalgams are immersed in boiling water they become soft and plastic again and it is then possible to work or mold them into any shape and in due time they will once more become very hard. These amalgams were in times past largely used in

⁴ To make Lipowitz' alloy melt together 15 parts bismuth, 8 parts lead, 4 parts tin and 3 parts cadmium.

making *fool's gold* for jewelry but their real value lies in the fact that they make an excellent cement for glass, porcelain and the metals.

(1) *Vienna metal* or *imitation gold* is the kind of copper amalgam that is or was used for making imitation gold jewelry. It is formed of 86.4 per cent powdered copper and 13.6 per cent mercury. It takes a fine polish and to keep it from turning black the jewelry should be given a thin coat of lacquer, or, better still, electroplated with gold.

(2) *Metallic mastic* is the kind of copper amalgam that is used for cementing glass, porcelain and metals. It is made of 30 per cent powdered copper and 70 per cent mercury. For repairing broken glass and porcelain the edges of these must be heated to about 350 degrees centigrade, or 660 degrees Fahrenheit, and the amalgam must be heated until it flows freely. It is then applied to the edges of the pieces to be joined and pressed tightly together. To cement metals with it, the surfaces must be clean and then heated between 80 and 90 degrees centigrade, or 176 and 194 degrees Fahrenheit. This done, apply the melted amalgam to the surfaces and clamp them together until it is hard.

Gold Amalgams.—Gold dissolves so easily in mercury that to make an amalgam you need only to drop the former into the latter at room temperature. The better way, however, is to use powdered gold, melt it in a crucible and then stir in the mercury with an iron rod. Gold amalgam was formerly much used for gilding objects but now they are usually coated with gold leaf or electroplated with gold.

(1) To make a *gilding amalgam* for coating metal

objects with gold use $66\frac{2}{3}$ per cent powdered gold or gold leaf and $33\frac{1}{3}$ per cent mercury. Give the object a coating of this and then heat it until the mercury is vaporized when the gold will remain in a coherent film on the surface.

(2) A *gold dental amalgam* for filling cavities in teeth was formerly much used because it hardens quickly and as it does so it expands. An amalgam of this kind can be made of 50 per cent gold and 50 per cent mercury.

An Iron Amalgam.—Iron and mercury are barely on speaking terms and it is, therefore, difficult to make an amalgam of them, but it doesn't much matter because it would be of but very little use. Amalgamation was formerly employed to give iron objects a thin coating of mercury before a gold or silver amalgam was applied to them.

To coat or amalgamate an iron object with mercury put 1 part of granulated zinc, or zinc shavings will do, $1\frac{1}{2}$ parts of hydrochloric acid, 2 parts of iron sulphate (green vitriol), 12 parts of water and 12 parts of mercury in a porcelain vessel and heat to boiling point. Now clean the metal object thoroughly, then rinse it in clear water and boil it in the above solution for about 10 minutes. On removing it from the vessel you will find it has taken on a coating of mercury and the gold or silver amalgam must be applied to it at once.

A Lead Amalgam.—This amalgam is easily made by (1) rubbing lead filings 25 per cent by volume and mercury 75 per cent by volume in a mortar, or (2) stirring melted lead with heated mercury. The chief use of lead amalgam is soldering lead by the *autogenous*

process, as the uniting of pieces of metal by simply melting them together, is called.

To do this kind of soldering the edges of the lead must be well cleaned and the lead amalgam applied to them. The edges are now brought together and a red-hot soldering iron run along the line of the juncture; thus the mercury will be vaporized and the finely divided lead of the amalgam will be melted and so make a solid joint.

A Magnesium Amalgam.—When magnesium is pure it will slowly dissolve in mercury at room temperature and quickly dissolves when the mercury is heated to its boiling point. When an amalgam is made of 5 per cent magnesium and 95 per cent mercury it swells up the instant it comes in contact with the air and loses its metallic luster. It decomposes water when it is thrown into it and, it follows, liberates the hydrogen just as sodium and the other alkali metals do.

Platinum Amalgams.—Amalgams can be made of platinum but they have not been used to any extent because of its high price. In practically all cases where a platinum amalgam could be employed the same end is far more cheaply attained by the process of electroplating.

Silver Amalgams.—Like gold, silver dissolves easily in mercury at room temperature but the action is greatly hastened by heating the mercury to its boiling point, then putting in some powdered silver and stirring thoroughly with an iron rod.

(1) To make a *silvering amalgam* for coating metal objects use 90 per cent pure powdered silver and 10 per cent mercury. Heat the latter in a crucible until

it is at its boiling point, then drop in the silver powder and stir thoroughly with an iron rod.

(2) To make a *silver dental amalgam*, or *succedaneum* as it is called, use 50 per cent ordinary coin silver reduced to a powder and 50 per cent mercury. It forms a hard amalgam and expands as it hardens.

Tin Amalgams.—Tin dissolves very easily in mercury and an amalgam can be made of them by simply rubbing them together in a mortar or by putting tin foil shavings in either cold or hot mercury. The length of time required for the amalgam to harden will depend on the proportions of the metals that are used. Tin amalgams are used for silvering mirrors, for filling teeth and for tinning small metal articles.

(1) To make a tin amalgam for silvering glass dissolve 75 per cent tin in 25 per cent mercury that has been heated to just below its boiling point, and stir with an iron rod. Mirrors are now generally made with silver amalgam as it gives a brighter surface than tin amalgam.

(2) An amalgam for filling teeth is made by dissolving 20 per cent tin in 80 per cent mercury. The excess of mercury must be gotten rid of by rubbing and kneading the amalgam. It takes a few days for it to harden into a solid mass.

(3) An amalgam for tinning small articles of iron can be made by dissolving 50 per cent tin in 50 per cent mercury. The articles to be tinned must be cleaned in a dilute solution of hydrochloric acid and then dipped into the melted tin amalgam.

A Zinc Amalgam.—This amalgam is used for covering the cushions of frictional electric machines. It

consists of 50 per cent zinc, 25 per cent tin and 25 per cent mercury. The zinc and tin should be powdered and put into mercury that is heated to about the boiling point.

CHAPTER XIII

HOW METALS ARE MINED

It is my purpose in this chapter to tell you about mines and mining. First of all, we get the word *mine* from the later Latin stem *mina* which means a *mine*¹ and this came from the root *mina plumba* which meant a *lead mine*. Now the word mine as we moderns use it has three different meanings and these are (1) a possessive adjective pronoun; (2) a hole in the ground from which ores and other mineral substances are dug, and (3) the act of getting the ore, or what have you, out of the aforesaid hole.

It follows, then, that if you find a mine and mine some valuable mineral from it it will be mine (meaning yours) except for some small part of it that you must cough up to the government and such other amounts of it as you will be forced to part company with in divers other ways.

What Mining Consists of.—Ordinarily we think of mining as the actual process of digging out the ore with a pick and shovel or with power tools but, as a matter of fact, it includes all the varied branches of the art which both precede and follow the actual work of getting out the ore. Named from the beginning to the end these operations are (1) prospecting, (2) exploration and (3) development; then comes (4) the mine itself, and (5) the working of it; finally, there follows

¹ The ancient Greek word for mine is *metallon*.

(6) the system of haulage and (7) the treatment of the ores.

Prospecting for Gold.—In the good old days when a man set out to find gold or other metals he was called a *prospector*. In those halcyon days the prospector was often *grubstaked*,² that is, some one furnished him with the necessary food and supplies so that he could go forth in quest of the golden fleece, and in turn the party of the second part was promised a share of his finds.

The shining yellow metal was usually the chief goal of the prospector—nearly all of the other metals having been found in the early days more by accident than design. If the prospector was seeking for free gold he made his way to and through a land where there were sand and gravel beds of ancient streams and rivers, or alluvial and glacial deposits, and these were and are known as *placers* by the miners in the western part of the United States and Canada. When he was seeking gold locked up in quartz he traversed a land where there was known to be gold-bearing quartz.

Exploring for Ore.—The prospector, like the cowboy, has all but vanished and the finding of not only gold but of all of the other metals is now generally done on the basis of big business. Rich individuals and corporations employ mining engineers and a field staff and these carry with them a complete equipment of apparatus and tools for testing and work.

To learn the formation of the ground as accurately

² So called because the lender *stakes*, that is risks, the *grub* which means the food.

as possible any one of several different methods is used. The first of these is known as *surface excavations*, that is, trenches are cut across the mineral zone. The second of these is termed *underground works*, and shafts may be sunk and even tunnels may be dug, so that the quantity and quality of the mineral can be ascertained. The third and chief method is *drilling*, and when this one is employed the ground to be explored is marked off into squares of 100 or more feet on the side. At the center of each one a drill hole is sunk. The material that is removed by the drill is called the *core* and this is tested and analyzed to ascertain its metal content.

There are two kinds of drills used for this purpose and these are (1) the churn drill and (2) the core, or diamond drill. The *churn drill* drills a vertical hole from 6 to 9 inches in diameter and to quite some depth, the mechanical arrangement being, in all essential respects, the same as that employed for sinking wells. The *core*, or *diamond drill* drills a hole from 1 to 4 inches in diameter and this it does at any angle and to any reasonable depth. An examination of the core removed by either of these drills reveals exactly the quality and indicates in a measure the quantity of the ore that there is in each square.

The Development of the Mine.—After the exploration of a field shows that it contains the desired ore and that it can be economically worked, the next step is to develop the mine. The development includes (1) the construction of the mine proper, (2) its drainage and (3) its ventilation.

The *construction* of the mine consists of digging the

shafts,³ entries,⁴ drifts⁵ and slopes⁶ and these must be lined and braced with timbers. The *drainage* comprises a system of drains that is put in to carry off the water that seeps into the mine. Where a mine opens on the side of a hill the water is easily drained off by an *adit*, that is a drift slope tunnel, but where it has a more or less vertical shaft powerful pumping plants must be installed to pump it out.

The *ventilation* of a mine is as necessary a part of its development as its drainage system, for the oxygen content of the air must be kept up and a constant circulation of the air must be maintained in order to carry off the dust and gases. In some mines it is possible to use a natural ventilating system and this is formed by surface openings at different elevations, but in others adits must be used and the circulation kept up by either force or suction fans.

Kinds of Mining and Mines.—There are three chief methods by which mining is carried on and these are known as (1) placer mining, (2) open cut mining and (3) underground mining. By *placer mining* is meant the working of gold-bearing sands and gravels, or *pay dirt* as the miner calls it, that are found on the surface of the earth, or very close to it, and the profit there is in it, as you may possibly have heard, is often very considerable.

³ An approximately vertical hole of limited area as compared with its depth.

⁴ An *entry* or *adit* is a nearly horizontal passage or tunnel from the surface to the mine proper.

⁵ A passage that follows the course of a vein or stratum.

⁶ An incline shaft, commonly the main incline in a mine.

*Placer Mining.*¹—This kind of mining falls under five heads and these are (a) panning, (b) hand sluicing, (c) hydraulicking, (d) dredging, and (e) drift mining. *Panning* is the most primitive method of placer mining and it consists of washing the sand, gravel, etc., in a common pan or skillet, so that the gold, which is the heaviest, falls to the bottom while the other material is carried away by the water.

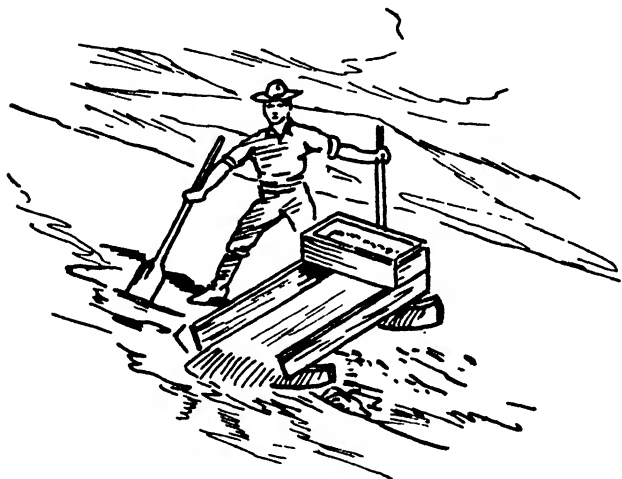


FIG. 37.—HAND SLUICING WITH A CRADLE ROCKER

By *hand sluicing* is meant that the pay dirt is washed in a *rocker* or *cradle* as shown in *Figure 37*, or in a *long tom* which is a long trough, the water being poured on the auriferous earth by hand, or, finally, in a *sluice*, which is a long trough with *riffles* in it for holding the mercury and which catches the gold; through the

¹ The word *placer* comes from the American-Spanish *placer* and this from the Spanish *placel* which means *sand bank*.

trough runs a continuous stream of water as shown in *Figure 38*.

Placer mining on a large scale is done by *hydraulic*-*ing* and this means that a gold-bearing gravel bank is washed down by a powerful jet of water from a nozzle called a *hydraulic giant*. The loosed gold-bearing dirt is then carried to the sluice by wheelbarrows, little cars, scrapers, a drag-line excavator, or a small steam shovel.

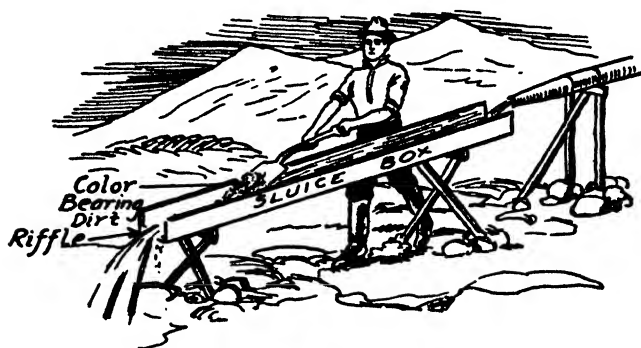


FIG. 38.—PLACER MINING FOR GOLD

The most economical method of placer mining on a large scale is *dredging* and this is done by a powerful dredging machine. As the gold-bearing earth is scooped up it is carried to a series of screens where the finer part of it, including the gold, passes through, and it is then washed in sluice boxes; these latter have riffles on their bottoms with mercury traps in them and when the gold comes in contact with *the quick*^s they form an amalgam. By heating this in a retort the mercury passes over in a vapor and the gold is left behind.

^s This is what the miner calls *quicksilver*, which, in turn, is the colloquial name for *mercury*.

Drift mining, or just *drifting* as it is called for short, is a combination of placer mining and underground mining. To reach the pay streak, which is somewhere between the surface and bedrock, a horizontal drift or a shallow vertical shaft is dug. If the surface gravel is frozen it must be thawed out before the shaft can be dug and this is done by building a fire on the spot and then keeping it going until the ground is thawed out a foot or so deep when the miner digs it out; then he builds another fire on it, and when this has thawed out he digs it out again. He repeats this operation until he has sunk a shaft deep enough through the frozen muck to reach the pay streak. The auriferous gravel is then hoisted to the surface and a pile made of it until warm weather approaches on horseback when it is washed in a sluice box.

Open Cut Mining.—The term *open cut*, or *open pit*, *mining* means the working of ores which lie close to or outcrop from the surface of the ground. Where the ore is covered with a layer of earth this latter is called *capping* or *overburden* and this must be removed to get at the ore. The capping or overburden may only be a few feet thick or it may be as much as 200 or more feet thick and the cut is sometimes three or four miles long.

After the capping or overburden has been stripped by means of either steam or electric shovels, the iron or copper ore is loosened and broken up by blasting and it is then loaded by power shovels on to regular railway cars that run directly into the cut so that the ore does not need to be transferred again. The only kind of a body of ore that can be profitably worked

by the open cut method is one that is fairly flat and of large size.

The Glory Hole or Milling Method.—This method is a combination of the open cut and underground methods as you will see from the cross-section picture of it which is shown in *Figure 39*. In this method

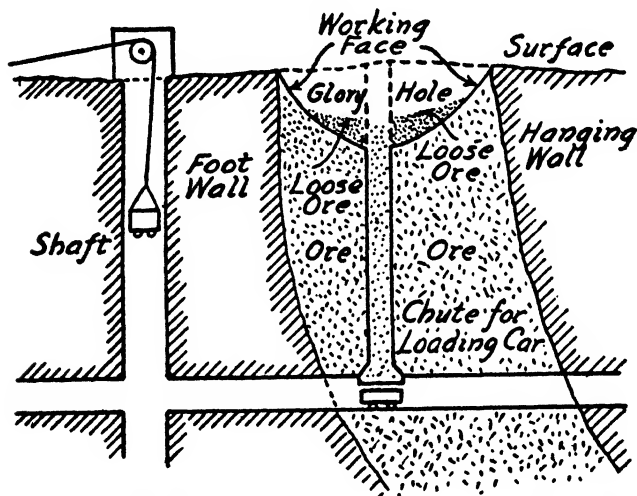


FIG. 39.—OPEN CUT MINING BY THE GLORY HOLE METHOD

the ore is mined on the surface in a hole, then dropped through a chute by gravity to a working level below, where it is loaded into small cars and then hauled to the surface through a shaft. The cavity formed by the working face is called *the glory hole* and the operation of getting the ore into the chute is called *milling* and there you have the origin of its several names.

Underground Mining.—There are three general methods employed for underground mining and these

are known as (1) the stoping method, (2) the top slicing method, and (3) the caving method.

The Stopping Method.—The word *stope* comes from the Middle English *stape* and this means *step*, and, it follows, the stopping method is one in which the ore is taken out stepwise, the excavation forming a rude

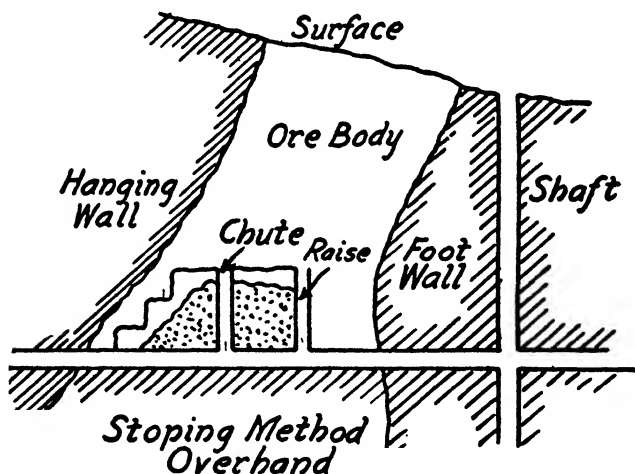


FIG. 40.—UNDERGROUND MINING BY THE OVERHEAD STOPPING METHOD

stairway. This kind of mining is generally used where the ore vein is very thick and is either vertical or greatly inclined. (See *Figure 40*.)

Stopping methods are of three kinds and these are (a) breast stoping, (b) underhand stoping and (c) overhand stoping. *Breast stoping* is used where the ore deposits are in the form of beds, or are flat dipping. The chief method of breast stoping is known as the *room and pillar method*. In this method the ore

is excavated in rooms and these are separated by pillars as shown in *Figure 41*.

In *underhand stoping* the stairway is like an ordinary one and is therefore worked from the top down.

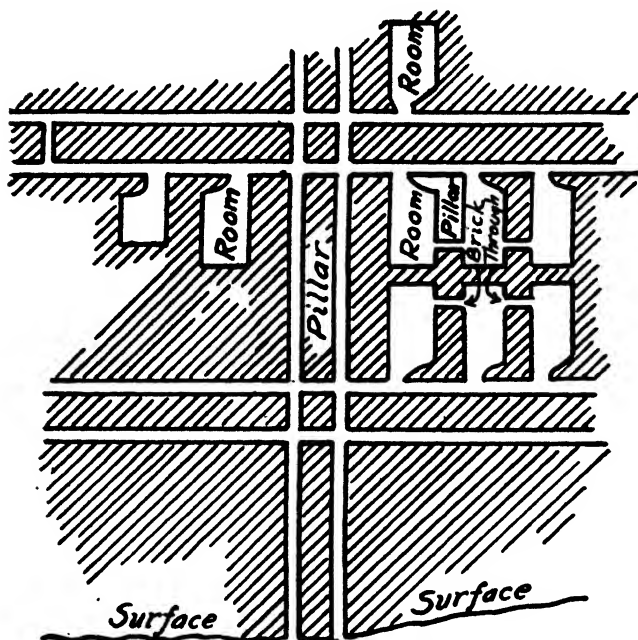


FIG. 41.—UNDERGROUND MINING BY THE ROOM AND PILLAR METHOD

The ore that is mined between any two adjacent levels is dumped to the lowest, or *horizon level* as it is called, and from there it is hauled to the shaft where it is taken to the surface.

The Top Slicing Method.—This method is largely used for mining wide veins and large masses of iron, copper, lead and zinc ores. It consists of working the

ore from the top downward, the ore body being removed in successive horizontal slices which are 10 or 12 feet thick. The first slice that is taken out is the one on which the capping or overburden rests and as the ore is removed the latter is held up and in place by posts.

The floor of the next slice is covered with *lagging*, that is, a mat made of timbers, and this is done to prevent the capping or overburden from mixing with the ore when it caves in on it. The posts are then shot out by small charges of an explosive when the capping or overburden caves in and falls on the mat. This operation is repeated, one slice being taken out after another, until the bottom of the vein is reached.

The Caving Method.—Where the ore to be mined is fairly hard and has a capping or overburden that will cave in the caving method is used. This consists of the closing or caving-in of the worked out levels of the mine, and forcing the ore under it to fall. To do this a great block of the ore has its supports removed from it by blasting when it falls with enough force to be broken into pieces that are sufficiently small to be easily handled. The caving method does away with much of the labor and at the same time a great deal of the blasting explosive is saved.

Kinds of Mine Equipment.—Various kinds of equipment are needed for the operation of the mine underground and this includes (1) pumps for drainage; (2) pumps for ventilation; (3) instruments for testing ventilation; (4) portable mine lamps; (5) electric service equipment; (6) drills, blasting apparatus

and explosives for rock excavations; and (7) mine rescue apparatus.

Mine Drainage.—Water finds its way into mines through various channels, and it is drained off by different methods. Among the drainage schemes are those of (1) *grouting*, that is thin mortar for filling in crevices and holes; (2) underground dams; (3) drainage tunnels; (4) siphons; (5) hoists; and (6) pumps.

The pumps used for drainage are of two types, (1) *plunger pumps* and (2) *centrifugal pumps* which are operated by steam, compressed air or electricity. Since nearly every mine at the present time is electrified, steam and compressed air pumps are not used to any great extent, and, it follows, that they are electrically driven. *Station pumps*, that is those which are stationary, are of the plunger type, while *gathering pumps*, that is those which are portable, are of the centrifugal type.

Mine Ventilation.—Mine air contains more moisture and several impurities which are not found in normal air. Among these are smoke and gas from blasting; the two chief kinds of the latter are carbon monoxide (CO), a very poisonous gas,⁹ and carbon dioxide (CO_2), a non-poisonous but irrespirable gas¹⁰ that is given off by man, animals and flames. Lesser sources of pollution are the excretions of man and animals, rotting timber and smouldering fires. What is called *fire damp* is chiefly methane (CH_4), and when this is mixed with air an explosive gas is formed.

⁹ This is because it combines with the hæmoglobin of the blood and expels the oxygen from it.

¹⁰ This is formed when firedamp explodes and, hence, it constitutes part of what is called the *afterdamp*.

Instruments for Testing the Air.—There are several means employed for testing the condition of the air in mines, and these have to do with (1) its current velocity; (2) its pressure, and (3) its purity. The current velocity is measured by means of (a) a *pitot tube*; ¹¹ (b) an *anemometer*,¹² or *wind gage*; (c) roughly, by observing the speed at which a lamp must be moved to keep the flame straight up, and (d) by observing the rate at which smoke is carried along.

For determining the pressure of the air a *manometer* or *wind gage* is used. To measure the amount of moisture there is in the air a *barometer* or a *hygrometer* is employed; of the former there are two kinds and these are (a) the *mercurial barometer* and (b) the *aneroid barometer*; there are also two kinds of the latter, (a) the *dry hygrometer* and (b) the *wet hygrometer*.

Methods of Ventilation.—Ventilation by the natural circulation of the air is employed in practically all metal mines but where a forced circulation is needed blowers are used, which are either of the propeller or centrifugal type. Where a temporary forced circulation is required as, for example, if there should be a breakdown of the regulation service, steam jets or compressed air jets, or the *trompe*, which is a hydraulic box ventilator that sets up an air current by falling water, are used. Where blowers are employed, these are either of the centrifugal or the impulse type.

Portable Mine Lamps.—The mine lamp is, of course, used for lighting up the area in which the miner is work-

¹¹ Pronounced *pe-to*. It was invented by Henri Pitot, of France, about 1750.

¹² From the Greek word *anemos* which means *wind* and *metron* meaning *to measure*.

ing and it may be either (1) of the oil burning kind, or (2) a portable electric one. If it is the former then it must be so made that it will not ignite the fire damp. This kind of a lamp is also used as a ready means for testing the presence of fire damp.

There are numerous types of safety lamps but the original one was invented by Sir Humphry Davy. The flame is enclosed in a fine wire gauze cage which, owing to its rapid cooling effect, prevents the flame from passing through it. If there is fire damp in the air, it passes through the gauze to the inside and there burns with a bluish cap over the flame. When this takes place the miner knows that the condition of the air is such that it is likely to explode.

Electric Service Equipment.—This consists of the underground transmission lines for carrying the current for (1) lighting and power purposes, and (2) for the telephone and signal systems.

Rock Excavation Methods.—For rock excavations, that is loosening and breaking up the rock ore in mines, drills and explosives are used. Various kinds of drills are used which are operated by (1) hand, and (2) power, i.e., compressed air or electricity. Holes are drilled in the rock, then an explosive is put into it, and this is fired by an electric spark.

There are three general kinds of explosives that are used in mining operations, and these are (1) black blasting powder, (2) gelatine dynamite and (3) gelatine nitroglycerine. The powder is a low explosive, and the dynamite and especially the nitroglycerine are high explosives. The kind of explosive that is used depends

on several factors, the chief one of which is the cohesive strength of the rock.

Now there are three ways to fire explosives and these

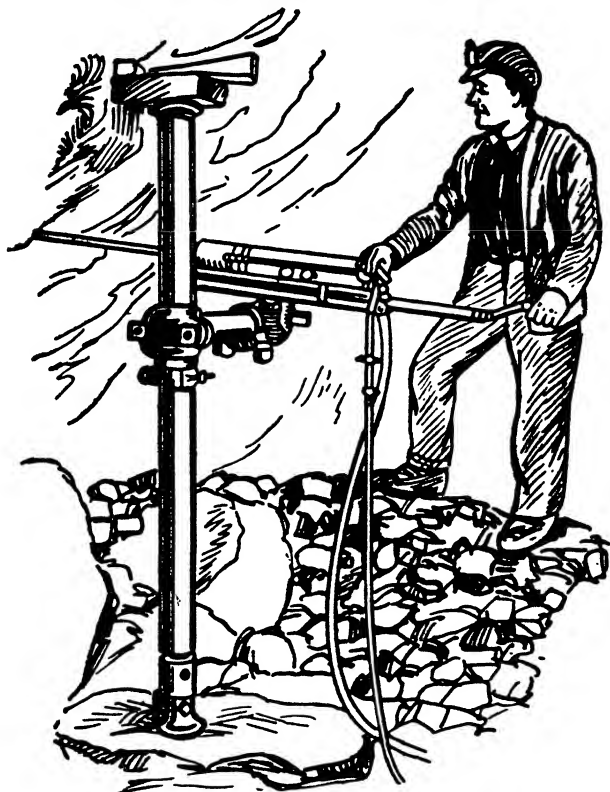


FIG. 42.—AN INGERSOLL-RAND MOUNTED DRIFTER DRILL, OPERATING ON AN ORE BODY

are with (1) a miner's squib, (2) a safety fuse, and (3) an electric blasting cap. The blasting machine is a little electric generator, with a pinion on the armature which meshes with a rack, so that when you push down on the handle attached to the latter the armature is

made to revolve and this sets up the current. The machine is pictured at A and B in *Figure 43*.

The connecting wires are made of stranded copper to make them flexible, and they are covered to insulate them. These wires lead from the machine to the electric blasting cap, and this is formed of a paper or copper shell which is closed at one end and then filled with

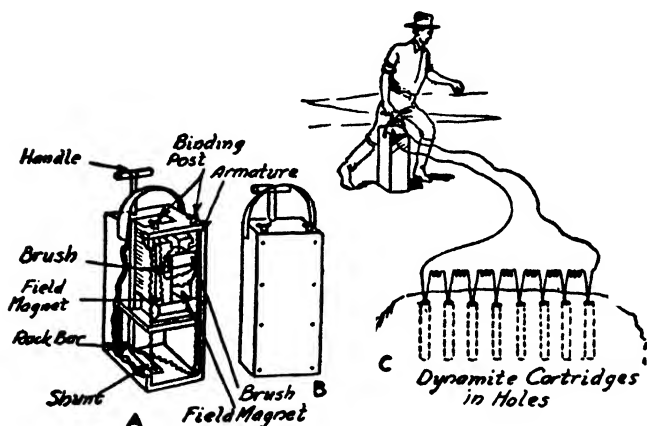


FIG. 43.—BLASTING OUT ORE WITH DYNAMITE

powder. The ends of the connecting wires are bridged across with a very fine wire and this sets into the charge of powder when the shell is sealed.

The explosive is put into the hole that has been drilled in the rock and into this is set the blasting cap. Now when the handle of the blasting machine is pushed down it generates a current and this heats the fine wire which, in turn, fires the powder. When the powder explodes the detonation sets off the explosive that is tamped in the hole. The way the electric machine and blasting cap are connected up is pictured at C.

Mine Rescue Equipment.—The equipment used for mine rescue work includes a varied assortment of devices and chief among these are (1) a portable oxygen breathing apparatus; (2) resuscitation apparatus for reviving men who have been overcome by smoke or gas; (3) portable telephone, signal appliances, guide ropes and other means of communication; (4) lighting apparatus such as safety lamps and portable electric lamps; (5) testing devices, such as gas indicators, birds and other small animals, etc.; (6) first-aid-to-the-injured appliances which include stretchers, medical supplies, etc.; (7) bratticing material for constructing temporary walls in a shaft or gallery; (8) fire fighting apparatus, which includes portable extinguishers, smoke helmets, pneumatic stoppings, hose, buckets, etc.

Mine Transportation Systems.—There are two general mine transportation systems and these are (1) mine haulage systems and (2) mine hoisting systems. By *mine haulage systems* are meant the more or less horizontal carriers of ore and these are divided into (a) underground haulage systems and (b) surface haulage systems. *Underground haulage* systems consist of means for transporting the ore from the face of the mine through a tunnel or adit to the surface, or of transporting it from the face to the shaft where it is hoisted to the surface.

Man and horsepower were used for underground haulage until about 1850 when the steam locomotive was tried out; then in 1885 the compressed air locomotive was employed; in 1888 the electric locomotive that had an overhead trolley was introduced; in 1890 the storage battery locomotive was first used (see *Fig-*

ure 44), and recently the gasoline locomotive was placed in operation, where the ventilation is good enough to carry the waste gases away. All of these types of locomotives except the steam locomotive are now in general

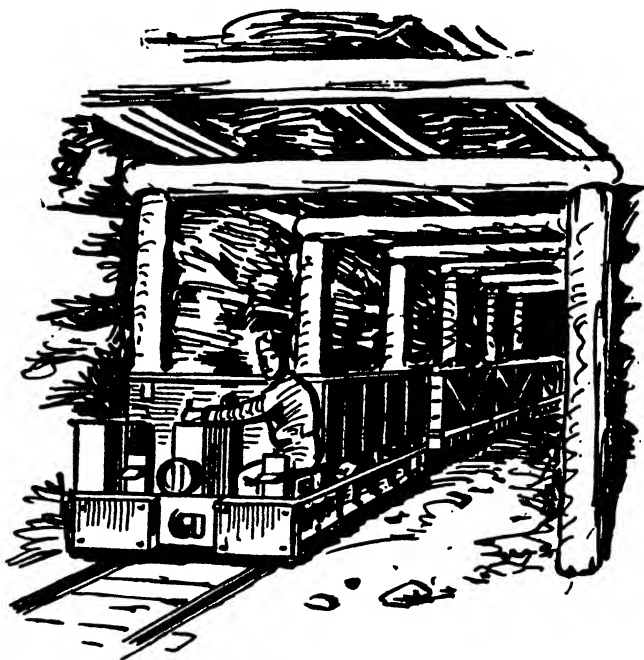


FIG. 44.—ELECTRIC LOCOMOTIVE FOR UNDERGROUND HAULAGE

use for underground haulage in mines throughout the world.

Surface Haulage Systems.—Systems for surface haulage are of practically the same type as those above described for underground haulage. The steam, compressed air, electric and gasoline locomotives are all in general use, while the motor truck, which is the latest

comer, has found favor at various mines in the more remote districts.

Other Haulage Systems.—Besides the various kinds of locomotives cited above there are other systems used for ore haulage and chief among these are (1) the *wire rope system* which is useful in inaccessible mountain regions; (2) *gravity planes* where the haulage is up an incline, and (3) the *belt conveyor*, where the

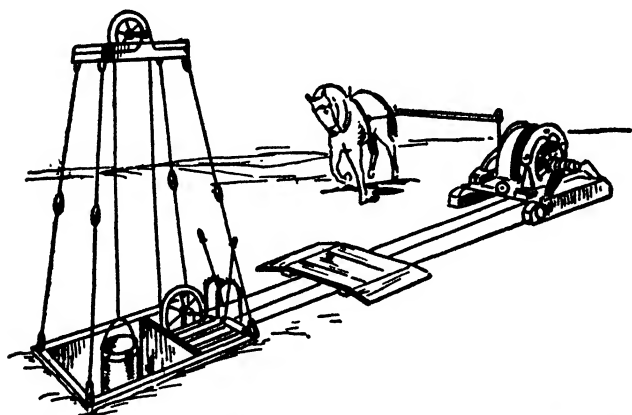


FIG. 45.—A WINDING GEAR WORKED BY HORSEPOWER, SUITABLE FOR PROSPECTING PURPOSES

incline is not more than 15 degrees. All of these systems are driven either by steam engines or electric motors.

About Hoisting Systems.—By *mine hoisting systems* are meant the more or less vertical carriers of ore and these consist of *winding plants* that reach from the lower levels of the mine up through the shaft to the surface. In the beginning of hoisting systems the *hand windlass* was used and this was called an *arm-strong hoist* for the very appropriate reason that the

power was developed by the strong arm of the miner who worked it.

After the hand windlass came the invention of the *horsewhim*, a crude mechanical contrivance that consisted of a long pole, or *sweep* as it is called, that was geared to a drum and upon which the hoisting rope was wound; to this sweep a horse was hitched and so as it traveled round a circle the drum wound up the rope, as shown in *Figure 45*.

With the advent of the steam engine the hoist was henceforth worked by it and from this small beginning the winding plant has been improved upon until at the present time some of the drums have a diameter of 30 feet and they can wind up a cable that is a mile or more in length. These great winding plants are used in various mines in Michigan and in the Transvaal in South Africa where the shafts are from 2000 to more than 5000 feet deep. At the present time both steam and electric power are used for driving them.

CHAPTER XIV

EXTRACTING THE METALS FROM THEIR ORES

AFTER the ore is mined it must be treated by various chemical and mechanical processes in order to extract the metal from the other constituents. The art of extracting the metals from their ores is called *metallurgy* and this word we get from the Greek roots *metallon* which means *mine* and *ergon* meaning *work*. Now in metallurgy the word *extraction* means, of course, the separation of a metal from its ore or the ore of some other metal, and the word *reduction* is generally used to mean the breaking down of an oxide into its constituent elements, *i.e.*, the metal it is formed of and the oxygen it is combined with.

There are several processes by which the various metals are extracted from their ores and the one that is employed depends, naturally, on the kind of metal and the other element or elements it is combined with which forms the ore. Thus (1) copper, mercury, bismuth, antimony, arsenic, silver, gold and the platinum family are found in their free states but they are also often locked up in rocks. When this is the case the latter must be crushed before the metal can be extracted from them.

(2) Iron, copper, tin, zinc, aluminum and manganese are usually found combined with oxygen, thus forming the *oxides* of these metals and they must be subjected to a sufficiently high temperature to decom-

pose them and set the metals free. (3) Iron, copper, lead, zinc, nickel, cobalt and antimony are often found in the form of *sulphides* and these must likewise be heated enough to vaporize the sulphur and so leave the metals free.

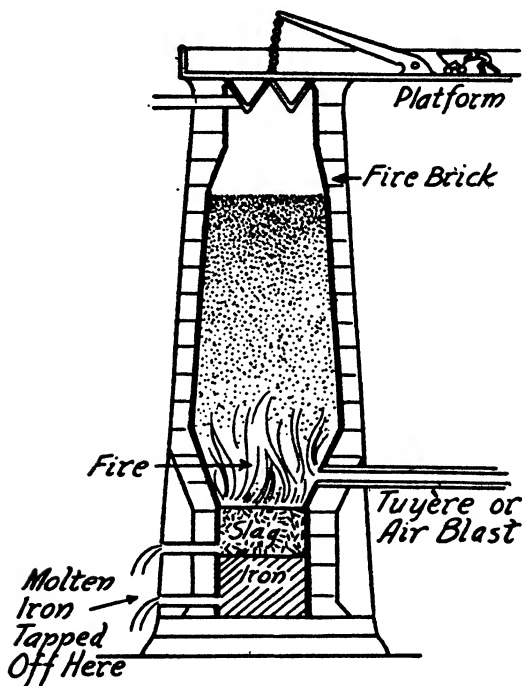


FIG. 46.—HOW IRON ORE IS REDUCED IN THE BLAST FURNACE

(4) Iron, copper, lead and zinc are also found in large quantities and barium, calcium, magnesium, manganese and some other metals are found in smaller quantities in the *carbonates* and these have to be heated in a blast furnace or in an electric furnace to separate the metals from the carbon. (5) Finally, when metals

cannot be separated from the other elements of their ores by using the foregoing methods they can often be had without difficulty by *electrolysis*, that is, passing an electric current through the melted chloride or other compound of them.

Extraction of the Common Metals.—*The Extraction of Iron.*—Some of the ores of iron are formed of oxides, some of sulphides, and some of carbonates. To get rid of the two latter nonmetals the ore is *roasted*, that is, heated to a temperature just below its melting point, and this expels them. The next step is to reduce the oxide of the iron and this is done in a blast furnace, a cross-section of which is shown in *Figure 46*.

It consists of an iron shell 18 to 22 feet in diameter and 80 to 100 feet high and this is lined with fire brick. Near the bottom of the furnace is an outlet to tap off the melted iron. A little higher up is another outlet to tap off the slag, and still higher up is a nozzle called a *tuyère*¹ which carries a blast of preheated compressed air to urge on the fire inside.

In this furnace are placed the alternate layers of coke and iron ore. If the ore contains carbonates, that is, lime or magnesia, a flux such as clay or silica, which latter is sand, is added to it, and, oppositely, if it contains clay or silica, lime or magnesia is mixed with it. Now when these substances are separated from the iron they form what is called *slag* and this combines with other elements there may be in the ore such as phosphorus, etc.

¹ Pronounced *two-yâr'*. It is a French word but of Teutonic origin.

As the ore is heated by the burning coke enough to melt the iron, it and the other elements fall to the bottom of the furnace and as the iron and slag will not mix they can be drawn off separately from the outlets which are provided for this purpose. To shut off the flow of the melted metal the openings are closed with dabs of wet clay and these are instantly baked into a hard mass.

The Extraction of Copper.—(1) Where copper in its free state is found it is usually mixed with rock and to obtain the metal the ore must be ground and then washed. The almost pure copper powder that results is mixed with a flux and this reacts with the other rock substances, or *gangue* (pronounced *gang*); this latter material, which cannot be melted at ordinary temperatures, is formed into compounds that can be melted at the temperature of melting copper. (2) When copper ores contain oxygen and carbon they are heated in a blast furnace and this removes the nonmetallic elements.

(3) To extract copper from a sulphide ore is a somewhat difficult matter for it usually contains considerable quantities of iron sulphide and this has to be separated out first by roasting and smelting in a blast furnace, as I have previously described for iron ores in general. The first step is to expel the sulphur and this is done by roasting the ore when only copper oxide and iron oxide, or *matte* as it is called, remains.

Next, these oxides are melted in a cupola or furnace, and then they are run into a large iron vessel, the lining of which contains silica. A blast of air that carries sand with it is then blown through the

liquid matte. This makes the iron combine with the silica and oxygen and the remaining sulphur passes off as a vapor. The iron silicate being lighter than the copper, it floats on top of it, when the latter metal can be drawn off. It is then cast into plates and refined by electrolysis.

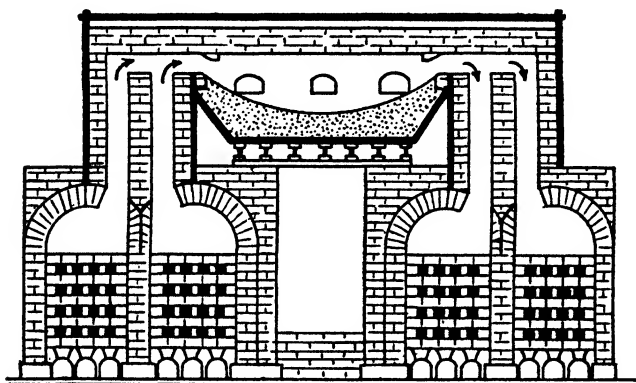


FIG. 47.—THE OPEN-HEARTH PROCESS OF MAKING STEEL

(4) A method that is largely used for extracting copper from low grade ores² is known as the *oil flotation* or *froth flotation* method. In this method the pulverized ore is mixed with a little oil and then agitated with water. The oil clings to the particles of copper but not to the rock, with the result that the former rises to the surface as a froth or scum while the latter sinks to the bottom, when it is then easy to obtain the metal.

The Extraction of Tin.—To obtain tin from its ore the latter is pulverized and then washed to remove

² Some ores contain only 2 per cent copper and 98 per cent rock.

the slate and granite from it. The gangue is roasted to get rid of the sulphur, arsenic and antimony, and this also converts any iron there may be in it into iron oxide. It is further treated with hydrochloric acid which changes any of the other metals there may be in it into their chlorides and these are washed away with water. Finally, only the tin oxide remains and this is heated in a furnace with coal which reduces it to its metallic state.

The Extraction of Lead.—As galena, which is the chief lead ore, usually has silver, copper, iron, zinc, and antimony mixed with it, the first thing that is done is to treat it to get rid of them. To do this the ore is heated in a stream of air which changes the lead into lead oxide. This latter compound is then reduced in a blast furnace with coal when the pure lead can be drawn off.

The Extraction of Zinc.—To extract zinc from its ores the latter are first concentrated by the oil or froth flotation process which has already been described in connection with the extraction of copper from low grade ores. The ores are then converted into zinc oxide; if the ore is a zinc carbonate one, this is done by burning it, and if it is a zinc sulphide it is roasted. (See *Figure 48.*)

The zinc, which contains small amounts of iron, lead, cadmium, arsenic and gallium, is obtained after the burning or roasting process by mixing it with powdered coal in a fire clay retort which is heated by gas. The resulting mixture is then distilled and as the reduction of the oxide takes place at a temperature above the boiling point of the metal, *i.e.*, 1300 to 1400 degrees

centigrade, or 2370 to 2550 degrees Fahrenheit the zinc is vaporized and it passes from the retort into an earthenware condenser where it is condensed first in the form of zinc dust, which consists of a mixture of zinc and zinc oxide, and then the zinc is melted.

The Extraction of Nickel.—The chief ore of nickel is *pentlandite* and this contains not only nickel and copper

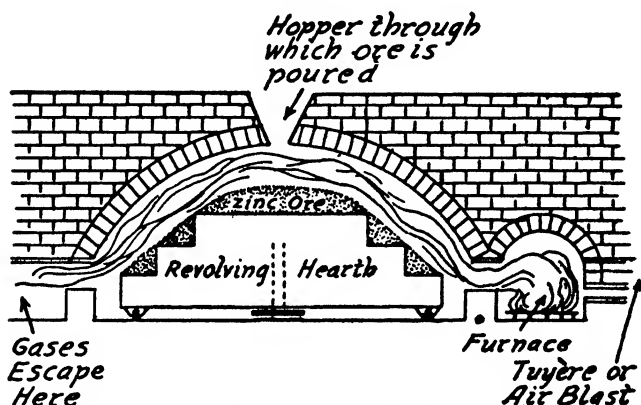


FIG. 48.—A REVOLVING HEARTH FURNACE FOR THE REDUCTION OF ZINC ORE

in equal amounts but also small quantities of iron and sulphur. To extract the two first named metals, the ore is roasted, then smelted and the reduction carried out in a *Bessemer converter*, which consists of an egg-shaped retort as shown in *Figure 49*. A blast of air is forced through, the ore and the oxygen of the air combine with the foreign substances and leave a nearly pure alloy of copper and nickel. The resulting metal is a natural alloy of equal parts of nickel and copper which is called *monel metal*.³ The nickel is then sepa-

³ See Chapter X.

rated from the copper by either the *Monde process* or the *electrolytic process*.

In the *Monde process* the nickel of the alloy is converted into nickel carbonyl, which is a compound of 1 part of nickel and 4 parts of a compound formed of

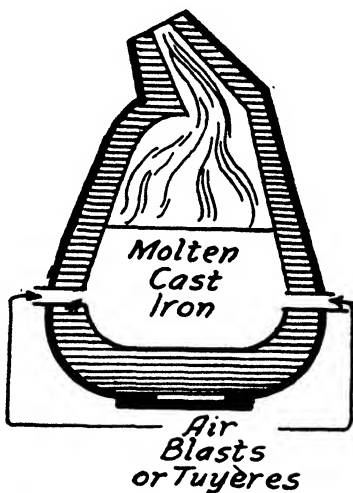


FIG. 49.—A BESSEMER CONVERTER FOR CHANGING CAST IRON INTO STEEL

oxygen and carbon, by heating it to about 50 degrees centigrade, or 120 degrees Fahrenheit, in a stream of carbon monoxide. The nickel carbonyl is a gas and this is then passed through a cylinder which is heated to 200 degrees centigrade, or 390 Fahrenheit, when it is decomposed and the nickel is deposited in its pure state.

The Extraction of Mercury.—This metal is easily obtained from the ore *cinnabar*, which is a natural mercuric sulphide. This is done by (1) roasting it when the sulphur passes off as sulphur dioxide, or (2) by mixing the ore with lime, which is calcium oxide, and heating

it in a distillation retort. When this latter method is used the calcium oxide combines with the sulphur, thus setting the mercury free, and this passes over as a vapor when it cools off and condenses into its liquid form.

(3) A third way to extract it is by the *Thornbill process* wherein the natural mercuric sulphide is dissolved in a solution of 4 per cent sodium sulphide and 1 per cent of caustic soda. Aluminum turnings are

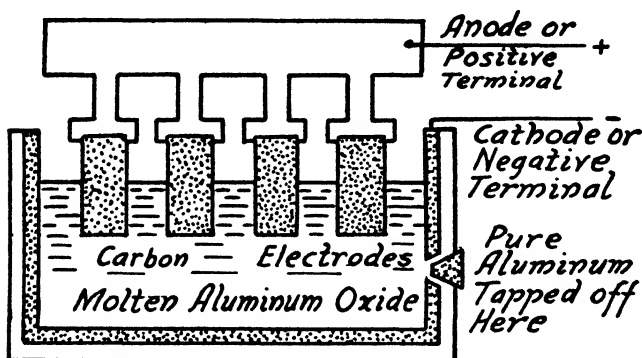


FIG. 50.—OBTAINING ALUMINUM BY THE ELECTROLYSIS OF ALUMINUM OXIDE

thrown into this solution and the mercury is precipitated by them.

The Extraction of Aluminum.—The metal is extracted at the present time in large quantities by the electrolysis of aluminum oxide (Al_2O_3), or *alumina* as it is called. This is dissolved in a batch of melted cryolite, (Na_3AlF_6),⁴ a mineral formed of sodium fluoride and aluminum. This process was invented by C. M. Hall, and the operation takes place in cells that are 3 by 5 feet on the sides, or larger; these are lined with

⁴ The melting point of this is 1000 degrees centigrade.

carbon and form the *cathodes*, or negative electrodes.

The *anodes*, or positive electrodes are formed of carbon rods, and these combine with the oxygen as it is set free. The melted aluminum⁵ sinks to the bottom of the cells and is drawn off from time to time while fresh alumina is added to the melted mass as it is needed. A current of 5 amperes per square centimeter⁶ of

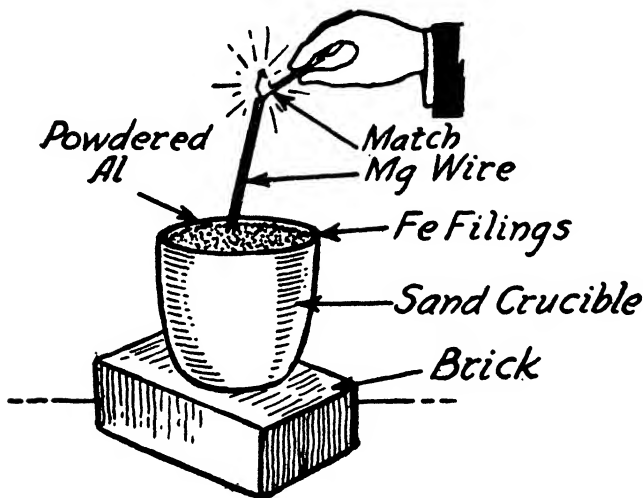


FIG. 51.—THE THERMITE PROCESS OF MAKING PURE METALS

cathode surface and an electromotive force of 5 or 6 volts keeps up the temperature of the melted materials and brings about their decomposition.

The Extraction of Cobalt.—The ores containing cobalt also have nickel in them but the former can be separated from the latter metal either by the reduction of the oxide by hydrogen or by the *thermit process*, or

⁵ The melting point of this is 659 degrees centigrade.

⁶ A centimeter is about $\frac{1}{2.54}$ of an inch.

Goldschmidt process, as it is often called from its inventor. This consists of mixing the cobalt oxide with powdered aluminum and when the last named metal is ignited it combines violently with the oxygen of the oxide, a high temperature is produced and this melts the metal and sets it free. *Figure 51* shows the thermite process.

The Extraction of Antimony.—The chief supply of antimony comes from the ore *stibnite* which consists largely of the black trisulphide of that metal. It is extracted by roasting the ore in air which drives out the sulphur and leaves antimony oxide. This is then mixed with carbon and heated to a high temperature and the pure metal results.

The Extraction of Bismuth.—The chief sources of bismuth are the ores *bismuth ochre*, which is the trioxide of the metal, and *bismuth glance*, which is a trisulphide. These ores also contain silver, nickel, cobalt and arsenic. Bismuth is extracted from these ores by roasting them in air so that the sulphur and arsenic are driven off and the metal becomes an oxide. The bismuth oxide is heated with carbon in the form of coal, together with iron and a flux; then the metal, more or less pure, is separated and drawn off in the melted state.

Extraction of the Noble Metals.—*The Extraction of Gold.*—Gold is found free in either alluvial sand with which it is mixed, or in quartz rock which is veined with it. In the former case the metal is separated from the sand by what is called *placer mining*, that is by the simple method of washing in a pan, cradle or in a sluice box, or by dredging, hydraulicking or other means, as explained in the preceding chapter.

Where the gold occurs in quartz rock the latter is pulverized in a *stamp mill*, that is, a machine in which the ore is crushed in mortars with heavy pestles. The pulverized quartz is then carried by a stream of water over a series of copper plates which are coated with mercury and this dissolves out a little more than half of the gold that was in the rock. The gold amalgam is then distilled—the mercury passes over as a vapor and the pure gold is left behind.

The lighter or *refuse ore*, as it is called, which contains the finer particles, or *tailings*, collects at the lower end of the washing apparatus and this is made to react with a dilute solution of sodium cyanide which is then exposed to the air. In this way the gold is oxidized by the air and at the same time it reacts with the cyanide and the products thus formed are sodium aurocyanide[†] and hydrogen peroxide.

The gold is separated out of the cyanide solution either by electrolysis, which process has already been explained, or by *cupellation*, which means that it is put in a small porous cup, called a *cupel*, and this is heated to a high temperature. In this way the lead, tin, copper and other metals that may be alloyed with it are oxidized and the pure gold is left behind.

The Extraction of Silver.—Silver occurs free in various ores but is often alloyed with gold and copper. It is also found alloyed with gold in ores and when this is the case the latter are crushed in a stamp mill; the metal or metals are then dissolved out with mercury and the amalgam thus formed is distilled, when the mercury passes over.

[†] Aurocyanide means gold cyanide.

Another method for the extraction of silver is to treat the pulverized ore with a dilute solution of sodium cyanide which reacts with the silver and converts it into silver cyanide but which has no effect on the gold. The silver cyanide dissolves in the excess of the sodium cyanide and forms a sodium silver salt which is combined with the radical made up of carbon and nitrogen. To precipitate the silver from the solution made with silver salt zinc is added to it. With some silver ores both of the above processes are carried on at the same time.

There are various processes used for the extraction of silver from ores which also contain lead, but the one known as *Parke's process* is chiefly in favor at the present time. It consists of smelting the silver and lead ore and mixing the melted metals with a little zinc. Now lead and zinc have very little affinity for each other and, it follows, they dissolve in each other to only the slightest extent. The zinc comes to the top and brings with it the silver and these two metals become solid while the lead is still in a melted condition.

The zinc silver alloy is removed and then heated in a furnace to a temperature just high enough so that any lead which may still cling to it will drain off. The final step is to distill off the zinc in a fire clay retort and then get rid of the remaining traces of lead by cupellation. Should there happen to be any gold alloyed with the silver it is separated from it by electrolysis, the bath being formed of a silver nitrate solution and the anode of the gold-silver alloy.

Extracting the Platinum Metals.—*The Extraction of Platinum.*—(1) To separate platinum from its asso-

ciated metals, *i.e.*, the other members of the platinum family, it is dissolved in *aqua regia* under pressure and the solution is then evaporated until it is dry and the residue, which contains platinum chloride, is heated to 125 degrees centigrade or 250 degrees Fahrenheit. A solution is formed of this product and ammonium chloride is added to it which precipitates a double chloride of the platinum. This salt is then heated to a high temperature and the residue that is left is platinum. (2) Moissan has obtained pure platinum by distilling its alloy in the electric furnace, and also, (3) by heating platinum fluoride to a red heat.

The Extraction of the Uncommon Metals.—*The Extraction of Arsenic.*—Arsenic is obtained by roasting arsenical pyrites and then putting these into a distillation retort. On heating the latter the arsenic is set free and vaporized; it is then condensed into the solid form of the metal while the ferrous sulphide is left behind.

The Extraction of Beryllium.—This rare metal is obtained by the electrolysis of the double fluoride of beryllium and potassium.

The Extraction of Cadmium.—This metal is found in zinc ores and is obtained as a by-product in the distillation of zinc.

The Extraction of Chromium.—The thermit process is used to obtain this metal, that is to say, chromium oxide is mixed with powdered aluminum and the latter is ignited. The intense heat produced makes the oxygen of the former combine with the aluminum so that aluminum oxide is formed and the chromium is melted and set free.

The Extraction of Columbium.—The first to extract the metal columbium was H. E. Roscoe. He obtained it by passing a mixture of the vapor of columbium pent-chloride and hydrogen through a red-hot glass tube and then strongly igniting the crust in a current of hydrogen in a porcelain tube until the hydrogen chloride was no longer produced, when the metal appeared as a bright, steel-gray, shining crust.

The Extraction of Germanium.—This rare metal is extracted from the minerals argyrodite and euxenite, from crude zinc oxide and other sources by distilling germanium tetrachloride, when the metal is set free.

The Extraction of Manganese.—There are several ways by which manganese can be had from its ores and chief among these are (1) by the reduction of its oxide with carbon in the electric furnace; (2) by the thermit process, that is, mixing its oxide with powdered aluminum and firing the latter, and (3) by melting manganese chloride and mixing it with magnesium when the manganese separates out in a very pure state.

The Extraction of Molybdenum.—This metal can be obtained by roasting the ore, which is formed of molybdenum sulphide, in a current of air; then the sulphur passes off as a vapor and molybdenum oxide is formed. This latter compound is then mixed with oil and charcoal which is heated to a high temperature and the molybdenum is reduced to the metallic state.

The Extraction of Selenium.—There are two ways in which selenium is obtained: (1) by the electrolytic refining of copper from the mud that settles in the vats and (2) from the deposits that are thrown down in the chambers in the manufacture of sulphuric acid.

The Extraction of Tantalum.—This metal is produced by heating the double fluoride of tantalum and potassium in an electric furnace.

The Extraction of Tellurium.—Tellurium can be obtained by either (1) the reduction of tellurium dioxide, or (2) by melting bismuth telluride with sodium carbonate and carbon and then treating the resulting compound with water. The solution thus made contains sodium telluride and when this is exposed to the air the metallic tellurium is precipitated in the form of a gray powder. It may be purified by distillation in a current of hydrogen gas.

The Extraction of Thallium.—This metal is also extracted in three different ways and these are (1) by treating thallium iodide with metallic sodium; (2) from thallium sulphide by immersing strips of zinc in a solution made of the latter compound, so that thallium will be deposited upon the zinc in the form of a spongy mass, and (3) from the dust that is produced when iron and copper pyrites are roasted in the process of making sulphuric acid.

The Extraction of Titanium.—This metal is obtained by heating titanous chloride with metallic sodium.

The Extraction of Tungsten.—This metal is obtained by either (1) reducing tungstic oxide with hydrogen gas in quartz or iron tubes at a high temperature, or (2) by the aluminothermic reduction of the above named oxide.

The Extraction of Vanadium.—To obtain vanadium its oxide is reduced with carbon or aluminum powder in the electric furnace.

The Extraction of Zirconium.—This metal is had from either zirconium chloride or potassium-zirconium fluoride by the reaction of metallic sodium with them.

Extraction of the Alkali Metals.—This family of metals, which includes sodium, potassium, lithium, cesium and rubidium, was first isolated from its compounds by passing a current of electricity through them, but since then they have been obtained by other reactions.

The Extraction of Sodium.—(1) Davy obtained metallic sodium for the first time in 1807, and this he did by electrolyzing moist sodium hydroxide, or *caustic soda* as it is called. (2) Then Gay-Lussac and Thenard extracted it from caustic potash by decomposing it with a red-hot iron, and (3) Brunner obtained it by firing sodium carbonate with carbon in the form of charcoal. (4) It is now produced commercially by the Castner method of electrolysis.^a

The Extraction of Potassium.—(1) This metal was also first obtained by Davy and this he did by the electrolysis of moist potassium hydroxide, that is, *caustic potash*. (2) Potassium was formerly made for commercial purposes by heating a mixture of caustic potash and carbon; then the free metal was distilled over and collected in petroleum. (3) The electrolytic process has now come back into use, the electrolyte being formed of melted potassium chloride.

The Extraction of Lithium.—Davy isolated a minute amount of this metal by the electrolysis of lithium

^a This method will be found explained in detail in any college chemistry.

chloride and this is the method of obtaining it at the present time.

The Extraction of Cesium and Rubidium.—These two metals may be obtained by any one of the following methods, namely (1) by heating their hydroxides with magnesium powder, (2) by heating their carbonates with carbon, and (3) by the electrolysis of their chlorides.

Extraction of the Alkaline Earth Metals.—While the metals of the foregoing alkali family can be obtained in their free states by heating their carbonates with carbon, the alkali earth metals cannot be isolated by this method. This is largely due to the fact that their oxides cannot be melted and this prevents them from making perfect contact with the carbon. The way that is commercially employed to isolate these metals is by passing a current through their melted chlorides.

The Extraction of Calcium.—In extracting this metal from its melted chloride a little calcium fluoride is added to the latter to lower the melting point of it.

The Extraction of Magnesium.—Magnesium is obtained by the electrolysis of melted carnallite, a mineral formed of hydrous chloride of magnesium and potassium.

The Extraction of Strontium and Barium.—These two metals closely resemble each other and they are obtained in the same way, namely, by the electrolysis of their melted chlorides.

Separation of the Rare Earth Salts.—As you have seen from the *Tables of Rare Earth Metals* that are given in *Chapter VII*, there are two chief families or groups of them and these are (1) the *cerium family*

and (2) the *yttrium family*. Now the reason that the rare earths are divided into two families is, as the tables also show, because all of the natural oxides of them are mixed together with those of either cerium or yttrium.

To separate these oxides from the foreign substances with which they are mixed in the minerals is a comparatively easy matter for the chemist, but to separate the individual rare earth oxides from each other is a long drawn out and tedious series of operations. Having separated the oxides which are converted into other salts, such as the sulphates and chlorides, by the acids that are used as solvents for them, the next thing to do, and this is often quite as difficult, is to extract the individual metals from them.

Now it is not my intention to go into all of the minute details of how these rare earth salts are separated from their parent oxides, *i.e.*, *ceria* and *yttria*, or how the rare earth metals are extracted from their respective salts, as it would take a book the size of this one to tell the complete story; but what I shall try to do, however, is to give you a general picture of the chief processes that are used and the numerous operations that are necessary by which chemists accomplish these two results, together with the methods they employ for testing the final purity of the products.

Opening the Mineral.—The first thing that the chemist does when he wants to obtain a salt of a given rare earth metal is to *open the mineral* which contains the oxide of the metal he wants. To do this he crushes the mineral and then pulverizes it; then he makes a solution of it by treating it with either hot sulphuric

acid or hot hydrochloric acid. These acids dissolve all of the foreign matter but leave the salts of the rare earth metals as they are insoluble.

Fractional Crystallization.—The next step is to separate the salts from each other and the process by which this is done is known as *fractional crystallization*; this term means that the salts of the rare earth metals, each of which latter has an atomic weight that is slightly greater than the one before it (excepting yttrium), will crystallize and separate out in the order of its atomic weight. Now the process by which fractional crystallization, or *fractionating* as it is called for short, is usually done in two stages and these consist of the following series of operations as given by Schoeller and Powell in their book, *The Analysis of Minerals*.

The First Stage.—The original mixture of salts (*A*) is dissolved in a hot acid solvent and the solution evaporated until on cooling about one-half of the original mixture crystallizes out. After standing overnight the mother liquor (*B*) is decanted (that is, gently poured off) into a new vessel and this is then evaporated, so that about one-third of the remaining salt crystallizes on cooling.

The first crystals (*C*) are now dissolved in a hot solvent so that on cooling two-thirds of the mixture crystallizes out. Both vessels are now allowed to stand overnight; the liquor (*D*) from the evaporation of (*B*) is poured off from the crystals (*E*) and this is again evaporated; the liquor (*F*) from the recrystallization of (*C*) is poured on the crystals (*E*) and this is warmed until the crystals dissolve; if necessary, more of the

solvent is added, and the salts are allowed to crystallize out.

The crystals (*F*) are now redissolved and recrystallized as before. This process is continued in a like manner until about 20 fractions have been obtained, the first crystals in each series being recrystallized from a fresh solvent; the mother liquors from each crop being used to dissolve the next crop, and the final mother liquor being evaporated in stages.

The Second Stage.—In this stage the number of fractions is kept constant. The fractions numbered from 1 to 20 are heated until the crystals are dissolved and then evaporated so that on cooling about three-fourths of them separate out. The mother liquor from fraction 20 is poured into a new vessel (21), the liquor from 19 on the crystals in 20, that from 18 on to the crystals in 19, and so on down to the liquor from 1 which is poured on the crystals 2.

A new solvent is next put in the vessel 1 and the whole series from 1 to 20 is heated until the crystals dissolve, when they are again allowed to crystallize. The same process is gone through as in the first case, that is, the liquor from 20 is poured into 21, that from 19 on to the crystals 20 and so on. The crystals 1 are again dissolved in a fresh solvent and the entire series of operations is repeated.

After a time the crystals 1 become very small in bulk and they, therefore, miss a crystallization after which they are added to the crystals in vessel 2 and this one from this time on constitutes the *head fraction*. When the liquor in vessel 21 gets to a sufficient bulk it is added to the series and becomes the new *tail frac-*

tion. By continuing in this way 1, 2, 3, etc., appear at the end of the series; thus it is that after a time the fractions begin to get less as more and more pure salts are removed from each end. The diagram given in *Figure 52* will help you to visualize the above operations by which the salts are separated out.

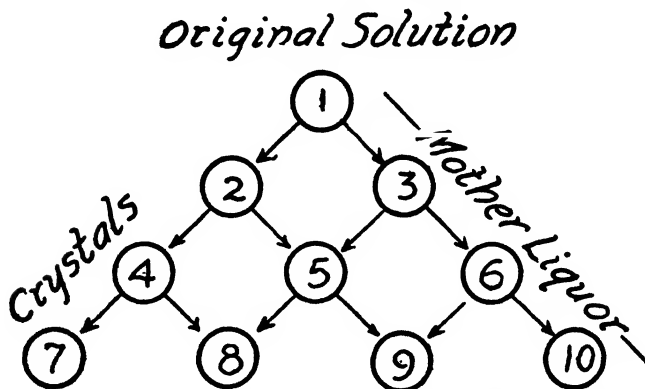


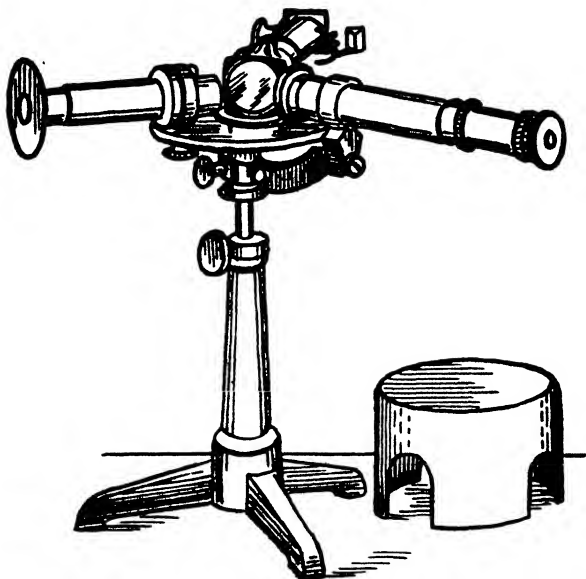
FIG. 52.—DIAGRAM OF A FRACTIONATION OF THE RARE EARTHS

From the complexity of the above operations it must be obvious why the most experienced chemist often has difficulty in obtaining pure salts of a given metal, and why he is frequently deceived in his deductions as to the metal it is formed of. It is these untoward factors which are chiefly responsible for many of the hypothetical metals which I have described in *Chapter IX*.

How the Fractionations Are Controlled.—By the term *control of the fractionations* is meant the testing of the rare earth salts, as the process of producing them moves along, to learn (*A*) the kind of a metal each one is made of, and (*B*) the degree of purity of each salt. The three principal methods of controls are

(1) the spectroscopic method, (2) the equivalent weight method, and (3) the magnetic susceptibility method.

The *spectroscopic method* consists of examining the salt with a spectroscope (see *Figure 53*), and its characteristic light lines can be observed. There are two



g. 53.—A SPECTROSCOPE FOR DETECTING THE PRESENCE OF METALS

(Courtesy of the Central Scientific Co., Chicago, Ill.)

kinds of spectra that are used for the examination of the salts of the rare earth metals and these are (a) the *spark spectrum* which is used for the detection of the metal in its salts, and (b) the *arc spectrum* which is used to test the purity of a salt or its metal.*

* You will find these methods explained in any textbook on college physics in the chapter on spectrum analysis.

The *equivalent weight method* consists of finding the weight of the element which will combine with 8 parts of oxygen or 1.008 parts of hydrogen. The equivalent weights of the different elements are so called because they are equivalent to the extent with which they combine with equal amounts of oxygen, or of hydrogen.

The *magnetic susceptibility method* consists, as its name indicates, of measuring the magnetic susceptibility of the rare earths as these vary quite widely one from the other. A magnetometer for the determination of rare earth metals is shown in *Figure 54*.

The Isolation of the Rare Earth Metals.—There are two general methods used in which the rare earth metals are isolated from their respective salts and these are (1) chemical processes, and (2) physical processes. There are three chief *chemical processes* employed and these are (a) fractional crystallization, (b) fractional precipitation and (c) fractional oxidation. The two chief *physical processes* are (a) fractional distillation, and (b) fractional electrolysis.

Now *fractional crystallization* is a process of separating out, that is, obtaining the metal you want which is in solution by a series of slow progressive crystallizations, the liquor of each one being poured off and evaporated for another crystallization. Isolation of a metal by *fractional precipitation* is accomplished by separating the metal from its solution by adding soluble salts to it, while *fractional oxidation* means that the metal is isolated by the successive oxidations of its salts.

The isolation of a metal by *fractional distillation* or *sublimation*, is accomplished by separating the dis-

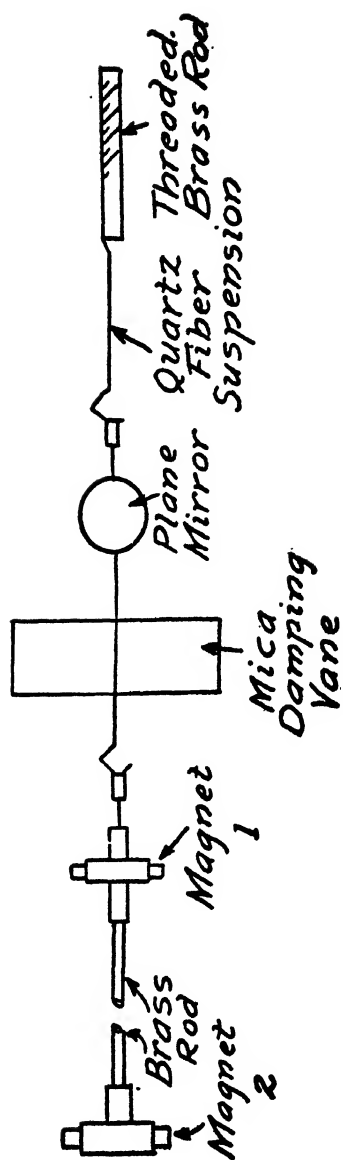


FIG. 54.—THE MAGNETIC MOVING SYSTEM OF A MAGNETOMETER

tillates which evaporate at different temperatures, and, finally, *fractional electrolysis* is performed by making a solution of a salt of the metal you want to isolate, immersing a pair of electrodes in it and connecting them to a suitable source of electric current. Both of the electrodes are often made of platinum but in some cases the cathode, or negative electrode, is formed of mercury and the anode, or positive electrode, is formed of platinum.

If you are interested in the precise *modus operandi* by which each one of the different rare earth metals is isolated from its respective salts you will find it in *Volume V* of Mellor's *Inorganic Chemistry*.

The Isolation of the Radioactive Metals.—The Metal Radium.—The chief mineral from which the metal radium is obtained is *pitchblende* and there is only about one-sixth of an ounce of radium in a ton of it, and it is only possible to get about half of this amount out of it. To do this the uranium that is in the pitchblende is extracted from it first and the remaining pitchblende is successively treated with hot caustic soda, hydrochloric acid and sodium carbonate.

The solid substance that remains contains radium carbonate and barium carbonate and there is also some calcium, lead, polonium and actinium in it. These latter metals are next removed and the above carbonates are converted into radium chloride and barium chloride so that these alone remain. As the barium chloride dissolves more easily than the radium chloride the former is dissolved out and only the radium chloride remains.

Now to isolate the metal radium from its chloride

is a full-sized man's job but it took a woman to do it and the way Madame Curie went about it was like this: She used the electrolytic process and when she passed the current through the solution of radium chloride the pure metallic mercury was deposited on the cathode, which was formed of mercury.

Next she heated the cathode, which was now formed of an amalgam of radium and mercury, in a little iron dish; this latter was placed in a tube made of quartz and was enclosed in a platinum tube which supplied a current of hydrogen, and the whole was placed in an electric furnace. When a temperature of 700 degrees centigrade was reached the mercury was volatilized and all that remained in the dish was a minute amount of dazzling white metal which was pure radium.

The Isolation of Uranium.—The oxides of this metal are found in pitchblende, carnotite and a few other rare minerals. The metal itself is obtained (1) by heating a mixture of one of its oxides with pure carbon or with powdered aluminum, or (2) by electrolyzing the double chloride of uranium and sodium.

The Isolation of Thorium.—There are several methods by which this metal can be separated out from its compounds, but all of them are difficult owing to the fact that it has a high melting point and its activity in combining with nitrogen, hydrogen, silicon and the metals.

It can be isolated by (1) the action of silicon and aluminum on thoria, i.e., thorium oxide, or on potassium thorium fluoride; (2) by passing the vapor of thorium iodide over a heated tungsten filament; (3) by the action of metal calcium on thoria; (4) by the treat-

ment of anhydrous thorium chloride in a steel bomb which has the air pumped out of it, and, finally, (5) by the electrolysis of thorium chloride in a mixture of fused sodium and potassium chloride in a graphite crucible.

CHAPTER XV

THE USES OF METALS

THE uses of the metals are so varied and numerous it would take a book of this size even to cite them briefly; this being true I shall have to be content to simply mention their chief uses. Generally speaking, metals are used for three different purposes and these are in (1) the arts, (2) the sciences, and (3) the industries. For whatever purpose metals are employed they are used in four different states and these are (a) in their pure state, (b) as alloys, (c) as amalgams and (d) as compounds.

Pure metals have very few applications in the industries, most of them being alloyed with other metals; the amalgams are chiefly used for scientific purposes except in mining operations, while the compounds are extensively used in the arts, sciences and industries.

THE COMMON METALS

The Uses of Iron and Steel.—*Iron* is the most common and useful of all the metals. *Pure iron* is seldom used for making things as it is too soft for nearly all practical purposes. The chief exception to this rule is piano wire which is about 99.7 per cent pure.

Cast iron may have a graphite carbon content that makes it soft and gray when it is called *gray cast iron*, or a combined carbon content when it is called *chilled*

cast iron. As its name indicates, cast iron is used for castings of every description. *Wrought iron* is used where a soft and tough iron that can be welded and forged is needed. It is used in the arts for all kinds of ornamental work and in the industries for drawing into wire and making bolts, chains, anchors and fire-bars.

Steel is an alloy of iron and carbon but different from ordinary iron it is almost free from phosphorus, sulphur and silicon. *Tool steel* contains from 0.9 to 1.5 per cent of carbon; *structural steel* from 0.2 to 0.6 per cent of carbon; *mild steel* 0.2 per cent of carbon and even less, and this is used for boilers, bolts, wire, and the like.

Bessemer and *open hearth steels* are used for light and heavy machinery castings, for shafts and it is rolled into rails and used for bridge and structural work.

Crucible steel is used for making razor blades and this contains 1.5 per cent of carbon; fine tools which contain 1 per cent of carbon; dies, pens, needles and cutlery contain 0.75 per cent of carbon.

Steel alloys and steels made for special purposes contain one or more of various elements such as manganese, nickel, chromium, tungsten, molybdenum and vanadium. *Manganese steel* contains from 7 to 20 per cent of manganese and is used for the jaws of rock crushers and safes. *Nickel steel* is used for armor plates, wire cables, bicycle tubing and propeller shafts.

Chromium steel has from 12 to 14 per cent of chromium in it and is used for acid-resisting vessels and for making *stainless steel cutlery*. *Tungsten steel* is used for making high-speed machine tools; it con-

tains from 16 to 20 per cent of tungsten, a little carbon, chromium and vanadium and the rest steel.

Chrome-vanadium steel contains 1 per cent of chromium, 0.15 per cent vanadium and the rest steel; it is used for the frames and axles of motor cars and connecting rods. *Invar steel* contains 36 per cent of nickel; it is nonexpansive and is used for meter scales and pendulum rods.

Iron Compounds.—In chemistry iron compounds go by the name of *ferric* and *ferrous*¹ compounds. The chief compounds of iron are ferric chloride ($FeCl_3$), which when made into a solution with alcohol is used in medicine as *tincture of iron*. Ferric ferrocyanide ($Fe_4(Fe(CN)_6)_4$) has a brilliant blue color and is known to painters as *prussian blue*. Ferric oxalate ($Fe_2(C_2O_4)_3$) is used for making blue print paper while ammonium-ferric citrate ($Fe(NH_4)_3(C_6H_5O_7)_2$), is employed instead of the oxalate for making commercial blue print paper.

Ferric oxide (Fe_2O_3) is *iron rust* and it is sold as *rouge* and *Venetian red*. Ferric thiocyanate ($Fe(CNS)_3$) furnishes a very delicate test for traces of ferric salts. Ferrous ferrocyanide ($Fe_3(Fe(CN)_6)_2$) has a deep blue color and is known as *Turnbull's blue*, and finally, ferrous sulphate ($FeSO_4$) is used in dyeing and for making writing ink.

The Uses of Copper.—On account of its resistance to the action of acids and gases copper is used for many kinds of vessels, for covering the roofs of buildings and the bottoms of ships. It is also extensively

¹ Ferric compounds are those which have a higher valence than ferrous compounds.

employed for engraved plates, electrottype reproductions and electroplating. Where water in mines has sulphuric acid in it which attacks steel, the pumps are made of copper. Pure copper is used as the positive element in gravity and other batteries, and pure copper wire, which is sold under the name of *magnet wire*, is used for all kinds of electric work.

Copper Alloys.—Alloys in which copper is the chief constituent are extensively used in the arts, sciences and industries. Bronze is used for making coins, medals and statuary and *brass* is used for making all kinds of scientific apparatus and light machine parts. *German silver* was formerly much used for making spoons and other tableware.

Copper Compounds.—In chemistry copper compounds go by the names of *cupric* and *cuprous compounds*. Cupric acetate ($\text{Cu}(\text{C}_2\text{H}_3\text{O}_2)_2, \text{H}_2\text{O}$) is known as *verdigris* and it is used for making green paint; it is also used in preparing *Paris green* which is chiefly employed for exterminating potato bugs and other insects and for killing parasitic fungi. *Scheele's green* is an arsenite of copper and is a poisonous green pigment, but it is little used at the present time.

Cupric chloride (CuCl_2) is used as a reagent, a mordant in the dye industry, in making sympathetic inks, as a disinfectant and in the manufacture of aniline dyes. The chief use of cupric oxide (CuO) is in the analysis of compounds of carbon. Cupric hydroxide ($\text{Cu}(\text{OH})_2$) is largely used for making *rayon*, that is, artificial silk, and for waterproofing paper.

Cupric sulphate (CuSO_4) is commonly called *blue vitriol* or *bluestone*. It is used in gravity batteries,

for electroplating solutions and as a mordant in dyeing. When a solution of it is mixed with *milk of lime* it is precipitated and this is known as *Bordeaux mixture*; it is largely used as a spray for grapevines and other plants to prevent the growth of fungi. Cupric sulphide (CuS) is used as an antiparasitic pigment for painting the bottoms of ships. Cuprous chloride ($CuCl$) in solution with hydrochloric acid is used for absorbing carbon monoxide from gaseous mixtures.

The Uses of Tin.—This metal is used for coating sheets of mild steel and then it is called *tinplate* which is used for making cooking and other utensils. Common pins are made of brass and coated with tin. When soft water contains dissolved oxygen it reacts on lead and for this reason tin pipes are used instead for carrying distilled water and for beer pumps. Tin is largely used for making tin foil and, in turn, this is used for wrapping candy and foods and for making electric condensers.

Tin Alloys.—The chief use of tin in making alloys are those of bronze, soft solders and fusible metals. It was formerly much used in amalgams for making mirrors.

Tin Compounds. — Ammonium-stannic chloride ($(NH_4)_2SnCl_6$), or *pink salt* as it is called, is used as a mordant on cotton and gives a red lake ² with alizarine. Stannic chloride ($SnCl_4$) when mixed with a little water solidifies to a soft crystalline mass which is known as *butter of tin*, and this is used as mordant in dyeing and calico printing. When a solution of it is added to a

² A lake is a pigment prepared by precipitating coloring matter with a metallic compound.

solution of sodium chloroaurate (NaAuCl_4) the metallic gold is set free while *purple of Cassius* is formed and this is used for gilding porcelain.

Stannic oxide (SnO_2), or *tin oxide* as it is called, is used for making white enamels, polishing glass, etc. Stannic sulphide (SnS_2) when heated in the presence of sal ammoniac* crystallizes and this is known as *mosaic gold* or *bronze powder*. Stannous chloride ($\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$) is used as a mordant in dyeing under the name of *oxymuriate of tin*. A solution of sodium stannate ($\text{Na}_2\text{SnO}_3 \cdot 3\text{H}_2\text{O}$) makes cotton goods noninflammable when they are dipped in it and then after drying are dipped in ammonium sulphate.

The Uses of Lead.—The ancients used this metal for weights, utensils and water pipes. Because it does not rust and acids have very little effect on it, it is used in sheet form for lining vessels and chambers in which sulphuric acid is made and kept. It is also largely used for plumbing pipes where the water is hard, and for covering electric cables, and making lead gratings for storage batteries. Finally, it is used for making lead sinkers, pans, pots, kettles and caldrons.

Lead Alloys.—When mixed with a little arsenic, shot and shrapnel are made of the alloy. It is used for type metal and stereotype plates, while soft solders, Babbitt metal and pewter contain large amounts of it.

Lead Compounds.—In chemistry the word *lead* and also *plumbic* are used to indicate their nature when combined with other substances. Lead acetate ($\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot 3\text{H}_2\text{O}$) is called *sugar of lead* and this is used as a mordant for dyeing and in calico printing.

* This is commercial ammonium chloride (NH_4Cl).

Basic lead carbonate ($2PbCO_3 \cdot Pb(OH)_2$) is the *white lead* of commerce and this is used as a pigment because it combines a pure white with great body, dries quickly and does not crack, but it is expensive.

Plumbic oxide (PbO) is *lead monoxide* and is a solid crystalline mass that has a yellowish-red color; it is sold as *litharge* and this is used for making glass, in glazing earthenware, in drying oils and, finally, as a starting point for making other lead compounds. When plumbic oxide is heated to a higher temperature than is used in making the litharge it forms a yellow powder called *massicot*, or *lead ocher* as it is sometimes termed. It is used as a pigment and drier and in the preparation of *minium* or *red lead* as it is commonly known; this is a red oxide of lead (Pb_3O_4) and is used as a pigment in the manufacture of glass, matches, storage batteries, etc.

The Uses of Zinc.—On account of its lightness *sheet zinc* is used in preference to lead for roofs, gutters and architectural ornaments. *Galvanized iron* is made by dipping clean sheet iron into melted zinc. Various iron objects are coated with zinc by cleaning and baking them in zinc dust and this process is called *sherardizing*. Zinc is used as the negative element in all primary batteries. For line cuts and coarse half tones zinc plates are used.

Zinc Alloys.—Zinc is used with copper for making all of the many different kinds of brass, and it is also a constituent of many fusible alloys.

Zinc Compounds.—Zinc chloride ($ZnCl_2$) is used in a solid form as a *caustic* and in solution it is injected into railway ties and other woods as a poison to kill

organisms which make them decay. It is employed as a *soldering solution* and this it does by dissolving the oxides which coat the surfaces that are to be soldered.

A hot solution of it dissolves *cellulose*, which is the chief constituent of both paper and cotton, and this takes on a gelatine-like form; when this is forced through a minute hole in a steel plate the cellulose issues forth in a thread and when this is carbonized the resulting filament is used for incandescent lamps. Finally, it is used in medicine as an *escharotic*, that is, as a caustic, and a weak solution of it is employed as an astringent and a disinfectant.

Zinc oxide (ZnO) is used as a pigment when it is called *zinc white* or *Chinese white*. It is also used for such widely diversified purposes as a filling for motor car tires and for filling teeth. When used for the latter purpose it is made into a paste by mixing the oxide with a strong solution of zinc chloride and it quickly sets. Zinc sulphate ($ZnSO_4$) is used in dyeing, in calico printing and, when made into a $\frac{1}{8}$ per cent solution with water, as an eyewash. Lastly, when zinc sulphide (ZnS) is mixed with barium sulphate it is used as a white pigment, in the manufacture of linoleum, rubber tires, etc. It has a greater covering surface than white lead, does not darken and is nonpoisonous but does not wear as well.

The Uses of Nickel.—Nickel is used for plating other metals, for making chemical and electrical apparatus, as a catalyst in the hydrogenation of oils which, in turn, are employed in the manufacture of *margarine*, and for making acid-resisting alloys and nickel salts.

Nickel Alloys.—Nickel forms a constituent part of

numerous noncorroding and high resistance alloys, chief among which are argentan, nickeline, ferro-nickel, platinoid, constantan, nichrome and rhostan. The four latter alloys are used for resistance coils in electrical apparatus.

Nickel Compounds.—There are two general kinds of nickel salts and these are (a) *nickelic salts* and (b) *nickelous salts*. The chief nickelic salt is nickelic oxide (Ni_2O_3) and this is used in storage batteries as an oxidizing agent. There are several important nickelous salts and chief among these are nickelous carbonate ($NiCO_3$) which is used in electroplating; nickelous chloride ($NiCl_2$) is used as a reagent for detecting the sulphocarbonates, as an absorbent for gas masks, for making sympathetic inks and for nickel plating solutions.

Nickelous cyanide ($Ni(CN)_2 \cdot 4H_2O$) is employed for electroplating and in metallurgy. Nickelous hydroxide ($Ni(OH)_2 \cdot 4H_2O$) is the starting point for making nickelous salts, and nickelous oxide (NiO) is also used for making various salts and as a green pigment in ceramics. Nickelous phosphate ($Ni_3(PO_4)_2 \cdot 7H_2O$) is used as a pigment when it is called *nickel yellow*, and for electroplating iron, copper and brass. Finally, nickelous sulphate ($NiSO_4$) is used in medicine as a tonic and sedative, a mordant in dyeing, for blackening brass and zinc and for nickel plating.

The Uses of Mercury.—On account of its high density and low vapor tension mercury is used for filling thermometers, barometers and manometers; ⁴ also for

⁴ An instrument for measuring the tension of gases and vapors.

mercury commutators for electrical experiments; mercury gages for steam pressure calorimetry tests; mercury pumps in which air and other gases are trapped and exhausted by a continuous or a broken stream of mercury, and, lastly, for mercury vapor lamps, interrupters and converters.

Mercury Amalgams.—Mercury will form amalgams with all of the ordinary and noble metals except iron and platinum and the platinum metals. Amalgams of tin, silver and gold are used by dentists; gold is extracted from its ore by amalgamating it with mercury; mirrors are backed with silver amalgam, and amalgamation of the zinc plates of batteries reduces the local action when in use and reduces the action of the acid on the plates when they are not in use.

Mercury Compounds.—Mercurous chloride ($HgCl$) is known in medicine as *calomel* and it is used as a purgative and tends to stimulate all of the organs producing secretions. Mercurous sulphide (Hg_2S) of the red kind is used in making vermilion paint. Mercuric chloride ($HgCl_2$), commonly called *corrosive sublimate*, is a virulent poison, a powerful antiseptic and an anti-syphilitic. It is also used in dyeing and other industries. When mercuric fulminate ($Hg(ONC)_2$) is suddenly struck it decomposes and it is, therefore, used in making *percussion caps*.

Mercuric iodide (HgI_2) when made into a solution with potassium iodide forms what is known as *Nessler's reagent*. It provides a very delicate test for ammonia and it is largely used in the analysis of water. When mercuric thiocyanate ($Hg(NCS)_2$) is made into pills and these are burned in air they leave an enormously

large amount of thin, cylindrical ash behind and these are called *Pharaoh's serpents*.

The Uses of Aluminum.—Not so long ago aluminum was among the least of the known metals but now it is to be found in every home in the form of cooking utensils which are of every kind. Aluminum foil is largely taking the place of tin foil. Aluminum wire is extensively used for electric transmission lines instead of copper wire. The metal is used for making cameras, opera glasses, bicycle, motor car and airship parts and for brewing vats. When the powdered metal is mixed with oil it is used as a silvery paint. Powdered aluminum is largely used for the manufacture of pure metals such as chromium, manganese, uranium, etc., by the *Goldschmidt thermite process*, and also for welding propeller shafts of ships and large castings of all kinds.

Aluminum Alloys.—A large part of aluminum is used in making steel for when 1 part of it is added to 1000 parts of melted steel, it combines with the gases and gives ingots that are sound and free from blow holes. *Aluminum bronze*, or *aluminum gold* as it is also called, has a magnificent golden color and is the finest bronze known. It is used for journal bearings, bells and ornamental articles of all kinds. *Magnalium* contains only 2 per cent of magnesium to 98 per cent of aluminum, but while pure aluminum sticks to the tools and is hard to polish the alloy is easy to work.

Aluminum Compounds.—There is a whole raft of useful compounds that have aluminum as their basis. Aluminum acetate ($Al(C_2H_3O_2)_3$) is used in medicine as a gargle, an astringent and as an antiseptic; it is also employed as a mordant in dyeing and by immersing

delicate cloth goods in a solution of it and then in an aluminum acetate solution they are made quite water-proof.

Aluminum hydroxide ($Al(OH)_3$) is a gelatinous white precipitate and it is used for purifying water for domestic purposes and also for sizing the cheaper grades of paper. Aluminum oxide (Al_2O_3) or *alumina* as it is called, is largely used for making synthetic rubies and sapphires. It is also converted into *aluminum* and this is used for artificial oil stones which, in turn, are used for sharpening tools.

Aluminum hydrated orthosilicate ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) when pure is known as *kaolin* or *china clay*; when a little fusible feldspar is added to it, it is used for making porcelain, china dishes and pottery. When it has other compounds mixed with it, it becomes common clay and this is used for making brick for buildings and tile for roofs and drains. Clays that are colored with iron and manganese oxides are used for pigments and these go under the names of *ocher*, *umber* and *sienna*. When the clay is a little purer than common clay it is called *Fuller's earth* and this is used for cleaning grease from cloth and wool and also as a filter to clarify oils.

In the olden days the pigment known as *ultramarine* was made of pulverized *lapis lazuli*,⁵ a rare mineral having a beautiful blue color. Ultramarine is now made by heating kaolin, sodium carbonate, sulphur and charcoal and the resulting compound has the formula of

⁵ In Latin *lapis* means *stone* and *lazuli* means *blue*. *Lapis lazuli* is the sapphire of the ancients. The less valuable stones were formerly used for making ultramarine.

($Na_4(Na_2S_3, Al)Al_2(SiO_4)_2$). This synthetic substance is used as laundry bluing, in making blue tinted paper and when mixed with oil for a rich azure blue paint.

Aluminum sulphate ($Al_2(SO_4)_3$) is sometimes called *concentrated alum* and it is used as a mordant in dyeing, in tawing skins and to give a surface to printed papers. It has largely taken the place of real alum for these purposes. It is also used for making precipitated hydroxide and this, in turn, is employed in dyeing, water purification and making paper.

The Uses of Cobalt.—In its metallic state cobalt is not used for commercial purposes.

Cobalt Alloys.—Cobalt is not used to any great extent in making alloys, the chief one being known as *cobalt bronze*.

Cobalt Compounds.—There are two general kinds of cobalt compounds and these are (1) cobaltic compounds and (2) cobaltous compounds, and it is the latter that are chiefly used in the arts and sciences. Cobaltous aluminate ($Co(AlO_2)_2$) is known as *Thenard's blue* and it is used as a blowpipe test for aluminum.

Cobaltous chloride ($CoCl_2, 6H_2O$) is used for sympathetic inks and hygroscopic indicators, *i.e.*, *weather forecasters*, since when the salt is hydrated (wet) it is red, and when it is dehydrated (dry) it is blue. Cobaltous oxide (CoO) when combined with zinc oxide forms a substance that is used as a green pigment which is of superior quality. When this oxide is melted with sand and potassium nitrate it forms what is called *cobalt glass*, and when this is pulverized it produces a blue pigment known as *smalt*, and this is used in china painting and by artists generally.

Cobaltous phosphate ($\text{Co}_2(\text{PO}_4)_2 \cdot 2\text{H}_2\text{O}$) is used in ceramics and the glass industry for producing light blue metallic colors. When it is burned with aluminum oxide it forms a dark blue pigment called *cobalt blue* or *cobalt ultramarine*. It is a permanent color and can be mixed with all mediums. Finally, the double nitrate of potassium and cobalt forms a bright yellow and nearly transparent pigment and this goes by the name of *cobalt yellow* or *aureolin*.⁶

The Uses of Antimony.—The metal antimony has no useful industrial application.

Antimony Alloys.—The alloys which contain antimony expand while they are solidifying and therefore give exceedingly sharp castings. Type metal, stereotype metal and britannia metal, which latter is largely used for tableware, contains antimony, as well as Babbitt metal and other anti-friction alloys.

Antimony Compounds.—When antimony trichloride (SbCl_3) is treated with a thiosulphate in solution a fine bright red pigment is formed and this is called *antimony vermilion*. Antimonyl⁷ potassium tartrate formula is our friend of bygone days known as *tartar emetic*. Antimony pentasulphide (Sb_2S_5) is used for vulcanizing rubber and gives an elastic, durable red variety of it.

Antimony oxide (Sb_2O_3) is called *antimony white* and this is used as a pigment. And, lastly, *stibine* (SbH_3) is a colorless gas formed of antimony and hydrogen. It has a characteristic odor, burns with a greenish

⁶ From the Latin *aureolus* which means *golden*.

⁷ *Antimonyl* is the radical SbO , that is, it is formed of antimony and oxygen.

flame and is deadly poisonous. It is used in Marsh's test for arsenic.

The Uses of Bismuth.—The metal itself has no industrial application.

Bismuth Alloys.—Like antimony, bismuth expands on cooling and, therefore, gives sharp castings. When bismuth is mixed with other metals that have low melting points they form alloys that melt at a lower temperature than that of boiling water. They are called *fusible metals* or *fusible alloys* and are used for filling teeth, making soft solders, taking impressions of coins and medals, safety plugs for steam boilers, automatic sprinklers, electric fuses, etc.

Bismuth Compounds.—The salts of bismuth are used in medicine, in making cosmetics, glass, porcelain, etc., and in calico printing. Bismuth chromate ($\text{Bi}_2\text{O}_3 \cdot 2\text{CrO}_3$) is called *bismuth yellow* and is used as a pigment. Bismuth benzoate ($\text{Bi}(\text{OOC}\text{C}_6\text{H}_5\text{O})_3$) is used internally in stomach disorders and externally instead of iodoform. Bismuth oxynitrate ($\text{Bi}(\text{OH})_2\text{NO}_3$) is used under the name of *subnitrate of bismuth* for treating certain kinds of indigestion and also in the manufacture of face powders.

The Uses of Chromium.—*The Metal.*—The only industrial use of chromium in its pure metallic state is for anodes in electroplating.

Chromium Alloys.—Chromium is largely used in making *chrome-steel* which, in turn is employed for armor-plate, etc. It is also a constituent of an alloy called *chromel*, which is highly resistant to rust, heat and the action of acids; it is used for wires, triangles, etc., in the laboratory.

Chromium Compounds.—Chromic anhydride (CrO_3) is often called *chromic acid*, but which it is not. It is much used as an oxidizing agent for organic substances. Chromic acetate ($Cr(CO_2CH_3)_3$) is used as a mordant by calico printers. Potassium chromate (K_2CrO_4) and sodium chromate ($Na_2CrO_4, 10H_2O$) form the starting points in making other compounds of chromium. Potassium dichromate ($K_2Cr_2O_7$) and sodium dichromate ($Na_2Cr_2O_7$) are employed instead of tanbark in tanning kid and glove leathers; this is known as the *chrome-tanning process* and it reduces the time of tanning from months to several hours. These chromates are also used with gelatine in making various kinds and colors of photographic *carbon prints*. Chromic fluoride ($CrF_3, 4H_2O$) is employed in dyeing, in printing cotton and coloring white marble.

Lead chromate ($PbCrO_4$) is used as a yellow pigment and this is sold as *chrome orange*; by treating it with lime water a brilliant orange color, called *chrome red* or *Derby red* is produced. Chromyl chloride (CrO_2Cl_2) is employed as a test for the presence of traces of chlorides in large amounts of bromides or iodides, or both; it is also a powerful oxidizing agent.

Chromic hydroxide ($Cr(OH)_3$) is employed as a mordant and is the active substance in the chrome-tanning process. Chromic oxide (Cr_2O_3) is used in making a green pigment called *chrome green*, and this, in turn, is employed in calico printing, in printing paper money, in ceramics and the glass industry. Chromic phosphate ($CrPO_4$) is called *Plessy's green* and *Arnaudau's green* and is employed as a pigment. Chromic sulphate ($Cr_2(SO_4)_3$) is the starting point

in the manufacture of chromic compounds and also of green inks.

Chromium-potassium sulphate ($K_2SO_4, Cr_2(SO_4)_3, 24H_2O$) is commonly known as *chrome alum* and one of its uses is that of a mordant in dyeing. Chromium trioxide (CrO_3) is one of the most powerful oxidizing agents. Chromous acetate ($Cr(C_2H_3O_2)_3, 3H_2O$) is a blue pigment that is used in calico printing and as a stain.

THE NOBLE METALS

The Uses of Gold.—Gold in its pure state is too soft to be used for commercial purposes and, hence, it is generally alloyed with a small percentage of some other metal or metals and these are usually copper or silver. It is, however, used for the anode in gold plating, for gold leaf for signs and gilding purposes generally, and also for the leaves of electroscopes.

Gold Alloys.—These are used for coinage, jewelry and objects of art.

Gold Compounds.—Auric chloride ($AuCl_3$) is used for toning silver prints in photography. Aurous iodide (AuI_3) is employed in dyeing to vary the shade. The aurocyanides like $K \cdot Au(CN)_2$, and auricyanides, like $K \cdot Au(CN)_6$ are used when made into solutions with water for electroplating with gold, or *electrogilding* as it is called. Aurous potassium cyanide ($KAu(CN)_2$) is also employed in electroplating and also as an antiseptic in medicine. About the only other gold salt that is in general use is sodium chloraurate ($NaAuCl_4$) and silver papers in photography are toned with it.

The Uses of Silver.—Silver is seldom used in its pure state except for making silver leaf and for anodes for electroplating.

Silver Alloys.—Silver is usually alloyed with a little copper to make it harder. Alloys of silver are used for coinage, jewelry and silver ornaments of numerous kinds as well as for silverware. Silver amalgam is used for making mirrors and filling teeth.

Silver Compounds.—Silver bromide ($AgBr$) is exceedingly sensitive to light and it is, therefore, used for sensitizing photographic dry plates and bromide papers such as *velox*. Silver chloride ($AgCl$) is also used for sensitizing silver photographic papers. Silver iodide (AgI) is used to some extent in photography and also in medicine, chiefly as an antisiphilitic. Silver nitrate ($AgNO_3$) is used in solution to sensitize silver photographic papers and it is also employed as the starting point for making other silver salts.

Lunar caustic * is silver nitrate cast into thin sticks and this is used to cauterize sores. It is used in treating diseases of the stomach and intestines, typhoid fever, epilepsy and tabes, which latter is a wasting disease. It is used for dyeing gray hair black, thus making old men young, as well as for dyeing furs, and, finally, it is employed as a reagent for testing, by their distinctive colors, silver orthophosphate (Ag_3PO_4) which is yellow, silver arsenate (Ag_3AsO_4), and silver chromate (Ag_2CrO_4) which is crimson. Ammono-silver nitrate ($Ag(NH_3)_2NO_3$) is used for silvering mirrors. Silver fulminate ($AgONC$) is a crystalline salt that is used on account of its violently explosive properties. Lastly,

* Also called *lapis infernalis* which is Latin for *infernal stone*.

potassium argenticyanide ($KAg(CN)_2$) is used for making plating solutions.

The Uses of Platinum.—Because of its small chemical activity, platinum is used for wire, foil, crucibles and other small chemical vessels and as a catalyzer in chemical processes. It is also employed as a dental filling, for spark points of induction coils and other electrical apparatus. Since the price of platinum has become higher than that of gold it is largely used for jewelry. It is used in Russia for coinage and we use it over here for cigar lighters.*

Platinum is the only metal that has exactly the same coefficient of expansion as glass and it was formerly fused into incandescent lamp bulbs to provide the electrical connection with the filament inside and the circuit outside.¹⁰ *Platinum sponge* occludes, that is, absorbs oxygen, hydrogen and certain other gases to a high degree and is employed as an oxidizing agent. *Platinum black* is used as a carrier of oxygen.

Platinum Alloys.—Platinum gold alloy has from 10 to 50 per cent platinum in it and from 90 to 50 per cent gold; it is used in some cases instead of the pure platinum. Platinum iridium has 90 per cent of platinum and 10 per cent of iridium, while platiniridium is a native alloy and contains platinum and iridium to-

* When a spiral of fine platinum wire is heated and then immersed in a mixture of air (oxygen) and alcohol vapor, the wire will continue to glow and it is on this principle that some cigar lighters are made.

¹⁰ Since the price of platinum has made its use for this purpose prohibitive, *Eldred's wire*, which has a core of nickel steel, over which is a jacket of copper and an outer sheath of platinum, has entirely displaced it.

gether with a little radium, ruthenium and copper. These alloys are largely used for pens as the iridium makes the metal very hard and resists the action of acids.

Platinum Compounds.—The compound known as barium chloroplatinate ($BaPtCl_6 \cdot 4H_2O$), or *platinum yellow* as it is commonly called, is used for coating fluorescent screens employed in X-ray work. Potassium platino-cyanide ($K_2Pt(CN)_4 \cdot 3H_2O$) and barium platino-cyanide ($BaPt(CN)_4 \cdot 4H_2O$) are both used in photography and for X-ray fluorescent screens. Platinic acid (H_2PtO_3) is used as a reagent for separating potassium from sodium, for *platinization*, which means the coating of surfaces with platinum, for toning photographs, in ceramics for metallic lusters and in the manufacture of *platinized asbestos*.

The Uses of Iridium.—This metal is chiefly used in the form of alloys with the other noble metals. The alloy known as *iridosmium* is used chiefly for pen points.

The Uses of Osmium.—The chief uses of osmium are as a catalyst, in making platinum alloys, for incandescent lamps and for pen points. The alloy *osiridium* is the same as iridosmium and is used in the preparation of osmium as well as for pen points. Osmic acid (OsO_4), which by the way is not an acid, is used in histology and stains tissues in consequence of its reduction by organic bodies to metallic osmium.

The Uses of Palladium.—Palladium in its metallic form is used as a catalyst and as a hydrogen absorbent. The alloys of palladium with gold and platinum are used in dentistry and for jewelry, and when it is alloyed with copper and silver it is used for making watches,

mirrors, fountain pens and pencils and surgical instruments.

The Uses of Rhodium.—Rhodium black is used as a catalyst, and rhodium alloys are employed in the manufacture of thermo-elements and astronomical measuring instruments.

The Uses of Ruthenium.—Metallic ruthenium has no commercial applications. The two chief ruthenium compounds are (1) ammoniated ruthenium ($Ru(OH)Cl_2, 3NH_3, H_2O$) which is a brown-red powder, and this is used as a reagent for pectin¹¹ and other organic compounds and as a microscopical stain, and (2) ruthenium sesquichloride (Ru_2Cl_6) which is used in chemistry as a catalyst and in medicine as an anti-septic.

THE ALKALI METALS

The Uses of Sodium.—*The Metal.*—Sodium in its metallic state has no commercial applications. It is used in the laboratory to demonstrate its great activity and this is done by dropping a piece of it in a dish of water.

Sodium Amalgam.—An amalgam of sodium is often used instead of the pure metal since the combination with mercury makes the reactions of the metal more easily controllable. (*See Potassium Alloys.*)

Sodium Compounds.—Sodium chloride ($NaCl$) is *common salt* and we not only use it to season our foods but as the starting point for making all the other sodium compounds except the nitrate. Sodium carbonate ($Na_2CO_3, 10H_2O$) is used in making soap, glass, paper,

¹¹ This is found in many vegetable tissues as a constituent of the cell wall or sap.

etc. It is used in medicine, photography, for softening water, and in the industries for cleaning purposes. Sodium alcoholate (C_2H_5ONa), or *sodium ethoxide* as it is also called, is used as a synthetic agent in organic chemistry and as a corrosive in surgery.

Sodium hydroxide ($NaOH$) is employed in the manufacture of soap, preparation of paper pulp and in various other commercial chemical processes. Sodium peroxide (Na_2O_2) is used for making oxygen and is sold in solid form for this purpose under the name of *oxone*; its chief use, however, is for bleaching and oxidizing. Sodium phosphate (Na_2HPO_4) is utilized in dyeing and in medicine as a purgative and as a cholagogue, that is, to promote the discharge of bile from the system. Sodium disilicate ($Na_2Si_2O_5$) is used for making *soluble glass*, or *water glass* as it is more generally called, and this, in turn, is employed for waterproofing and fireproofing wood and textiles and for preserving eggs. Sodium sulfantimonate ($Na_3SbS_4 \cdot 9H_2O$), or *Schlippe's salt* as it has been named, is used as a reagent for the alkaloids.

Sodium tetraborate ($Na_2B_4O_7 \cdot 10H_2O$), whose common name is *borax*, is used for hard soldering and welding iron. Borax is also mixed with glass in making enamels for cooking utensils, for bead reactions in chemistry and for preserving foods. Sodium thiosulphite ($Na_2S_2O_3 \cdot 5H_2O$) is commonly known as *hypo* and is used for fixing photographic negatives and prints and also as an *antichlor*, that is, a substance to remove the excess chlorine in textiles and paper pulp after they are bleached. Sodium sulphate (Na_2SO_4) is employed as a substitute for sodium carbonate in making cheap

glass, and, finally the decahydrate of sodium sulphate ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$), commonly known as *Glauber's salts*, is used for making soda by the *Leblanc process* and for making glass.

The Uses of Potassium.—Like the other alkali metals potassium in its metallic state has no commercial application, but like sodium it is used as an experiment to demonstrate its violent activity.

Potassium Alloys.—These are the liquid or semi-solid mixtures of potassium and sodium in the various proportions of 90 to 50 per cent of potassium and 10 to 50 per cent of sodium. Potassium also forms an amalgam with mercury.

Potassium Compounds.—Potassium bromide (KBr) is used in medicine as a sedative, and in photography for making emulsions and as a restrainer for developers. Potassium carbonate (K_2CO_3), or *potash* is used for making soap, glass, etc. Potassium chlorate (KClO_3) also called *oxymuriate*, is employed for making fireworks, the heads of Swedish matches, as an oxidizing agent and in medicine as a gargle. Potassium chlorate is employed as a reagent for alkaloids, phenols and indicans, also as an oxidizing agent, in ultimate analysis, that is, the determination of the elementary composition of a substance; in medicine as a diuretic and heart stimulant, in pharmacy for the manufacture of mouth washes and tooth pastes, and in the industries for explosives, fulminates and fireworks.

Potassium cyanide (KCN) is used in electroplating and in the *cyanide process* for the extraction of gold and silver from certain ores. Potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) finds employment in dyeing, photography,

as an oxidizing agent and in solution as an electrolyte for primary batteries. Potassium fluoride (K_2F_2) is used in the preparation of pure hydrofluoric acid, while potassium hydroxide (KOH), or *caustic potash*, or *potassium hydrate*, as it is also called, is used chiefly in making soap.

Potassium iodide (KI) is used in medicine for rheumatism and syphilis, and also in photography for gelatine emulsions. Potassium nitrate (KNO_3) is used chiefly in the manufacture of black gunpowder and touchpaper and also for preserving hams and corned beef. Lastly, potassium sulphate (K_2SO_4) is used in making alum and other compounds, as a purgative and as a direct fertilizer.

The Uses of Lithium.—*The Metal.*—Lithium in its metallic form has no commercial applications. It is sometimes used as a classroom experiment to show its activity.

Lithium Amalgam.—The metal forms an amalgam with mercury but it has no commercial use.

Lithium Compounds.—Compounds containing lithium are largely used in medicine, thus lithium acetate ($LiC_2H_3O_2 \cdot 2H_2O$) is employed as diuretic and anti-rheumatic; lithium arsenate ($Li_3AsO_4 \cdot \frac{1}{2}H_2O$) is used in gout, anemia, malaria, and as an anti-arthritis; lithium benzoate ($LiOCC_6H_5$) is employed as a sedative, as a diuretic and as a urinary antiseptic; while lithium bromide ($LiBr$) is used as a sedative. Lithium fluoride (LiF) is employed for making enamels in ceramics; lithium hydroxide ($LiOH$) is used as a reagent and in the manufacture of lithium salts of various kinds, and, finally, lithium nitrate is employed in

making *red fire* for fireworks and as a salt in artificial mineral waters.

The Uses of Rubidium and Cæsium.—*Their Compounds.*—The chief uses of these two alkali metals are limited to a few of their salts. Rubidium ammonium bromide ($RbBr, 4NH_4Br$) is used in medicine as a hypnotic, that is, a sleep producer, and rubidium hydroxide ($RbOH$) is employed in the manufacture of various other rubidium salts and in making glass.

The metal cesium is sometimes used instead of rubidium for they are much alike. Cesium salts are employed as reagents in micro-chemistry. Cesium ammonium bromide ($CsBr, NH_4Br$) is used as a nerve sedative in epilepsy; cesium bromide ($CsBr$) is employed in heart disturbances that are caused by nervousness, and, lastly, cesium carbonate (Cs_2CO_3) is used to charge soda water and various other light drinks with the necessary gas to make them bubble and fizz.

THE ALKALINE EARTH METALS

The Uses of Calcium.—*The Metal.*—The metal calcium is used in organic synthesis and as a reducing agent, but it has no applications in the industries.

Calcium Alloys.—Calcium is used in making a few alloys.

Calcium Compounds. — The following are the chief compounds of calcium. Calcium acetate ($Ca(OOCCH_3)_2, H_2O$) is used in the manufacture of acetic acid, acetone and in the dye industry. Calcium carbide (CaC_2) is used for generating acetylene gas. Calcium carbonate ($CaCO_3$), or *limestone* as it is called, is used in large quantities as building stone; when this

is burned it forms calcium oxide (CaO), or *quicklime*, and this, in turn, is employed for making calcium hydroxide ($\text{Ca}(\text{OH})_2$) or *slacked lime* and the uses of this compound will be described presently. Calcium chloride (CaCl_2) has a very great affinity for water and it is, therefore, employed as a drying agent. Calcium cyanamide (CaCN_2) goes by the common names of *cyanamid*, *nitroline* and *lime nitrogen*, and is sold as a fertilizer. Finally, calcium cyanide ($\text{Ca}(\text{CN})_2$), which is commonly called *powdered cyanic acid*, is used in fumigation.

Calcium fluoride (CaF_2) is employed as a flux to lower the melting point of metals. Calcium hydroxide ($\text{Ca}(\text{OH})_2$) is the starting point in making alkalies, cement and mortar, the removal of hair from hides previous to tanning them, for softening water, as a white-wash and as a *bleaching powder*; this latter compound is not only used for bleaching but as a disinfectant for destroying germs and disease.

Calcium hydride (CaH_2), whose common name is *hydrolyte*, is a very costly but portable source of hydrogen and is used chiefly for filling war balloons. Calcium oxide (CaO), or *quicklime* is employed chiefly in making calcium hydroxide ($\text{Ca}(\text{OH})_2$), or *slacked lime*, as I have already explained above and it, in turn, is used in large amounts for making mortars and cements and in smaller amounts in medicine. Calcium phosphate ($\text{Ca}_3(\text{PO}_4)_2$) is largely used in making phosphorus, phosphoric acid and as a fertilizer. Calcium sulphate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), or *gypsum* to give it its common name, is used for making *plaster of Paris* and this, in turn, is employed for making casts by

dentists, surgeons, sculptors and others; and, lastly, calcium sulphide (CaS) when moist is employed as a depilatory, that is for removing hair where nature thought it ought to be on the human body, and relegating it to the garboon.

The Uses of Magnesium.—*The Metal.*—The metal is used in the form of wire, ribbon and powder for making flashlights for photography, for signaling lights, for fireworks, and for igniting aluminum powder in the *thermit* process.

Magnesium Alloys.—When 2 per cent of magnesium is added to 98 per cent of aluminum an alloy called *magnalium* is formed and this is both easy to work on a lathe and to polish.

Magnesium Compounds.—Magnesium carbonate ($MgCO_3$) is made in large quantities and sold under the name of *magnesia alba*. It is used in medicine as a mild cathartic, as a cosmetic, for making tooth powders and for polishing silver. Magnesium chloride ($MgCl_2 \cdot 6NO_2$) is the starting point for obtaining the metal magnesium, and it is also used for making magnesium cements, composition floorings and artificial stones. Magnesium hydroxide ($Mg(OH)_2$) when mixed with magnesium chloride and a little sawdust is used as a plaster finish for buildings.

Magnesium oxide (MgO), or *magnesia* as it is called, is used for such widely divergent purposes as an antacid laxative and for lining of electric furnaces. Magnesium sulphate ($MgSO_4$) is commonly known as *epsom salts*, and is employed in the manufacture of sodium and potassium sulphates, in medicine as a purgative, in electric batteries, and for loading and sizing

cotton goods and textiles, bleaching solutions and, finally, in the paper and leather industries.

The Uses of Barium.—*The Metal.*—Barium is not used industrially in its metallic state.

Barium Alloys.—Barium is not employed as a constituent of either alloys or amalgams.

Barium Compounds.—Barium carbonate ($BaCO_3$) is used as a reagent, as a rat poison and in ceramics. Barium chlorate ($Ba(ClO_3)_2$) is employed in making green fire. Barium chloride ($BaCl_2 \cdot 2H_2O$) is used as a test for alum, a reagent for the detection of sulphuric acid, in veterinary medicines, in the manufacture of barium salts, as a poison for mice and rats and the softening and purification of water. Barium chromate ($BaCrO_4$) is a pure yellow powder that is used as a pigment and sold under various trade names such as *lemon yellow*, *barium yellow*, *baryta yellow*, *permanent yellow*, *barium chrome* and *yellow ultramarine*.

Barium fluoride (BaF_2) makes a strong antiseptic and is used as an embalming fluid and for enamels. Barium hydroxide ($Ba(OH)_2$) is employed as an alkalizing agent, as a flux for silicates, for saponifying fats, refining vegetable and animal oils, for neutralizing acids, and for refining sugar. Barium oxide (BaO) is largely used for making the hydroxides. Barium peroxide (BaO_2) is employed in making oxygen and also hydrogen peroxide and this, in turn, is largely used in medicine as an antiseptic and in the industries as an oxidizing and bleaching agent.

Barium nitrate ($Ba(NO_3)_2$) is employed in the manufacture of certain kinds of blasting powders. Barium sulphate ($BaSO_4$) is used as a pigment and

sold under the names of *baryta white*, *permanent white*, *blanc fixe*, etc. It is also used as the starting point in making other barium compounds, as a filling for glazed cards, and sometimes as an adulterant of white lead. Finally, barium sulphide (BaS) whose common name is *Bologna phosphorus*, is employed in making cheap luminous paints.

The Uses of Strontium.—*The Metal.*—The metal strontium has no industrial uses.

The Alloys of Strontium.—Strontium is not used for making either alloys or amalgams.

The Compounds of Strontium.—Strontium arsenite ($Sr(AsO_2)_2 \cdot 4H_2O$) is used as an insecticide; strontium bromate ($Sr(BrO_3)_2 \cdot H_2O$) in medicine as a tonic; strontium carbonate ($SrCO_3$) as a source for obtaining strontium salts, and strontium chlorate ($Sr(ClO_3)_2$), as a reagent and for making red fire for fireworks. Strontium hydroxide ($Sr(OH)_2$) is employed in the beet sugar industry for crystallizing the sugar from the molasses; strontium oxide (SrO) is also used in manufacturing beet sugar and, lastly, strontium sulphide (SrS) is employed as a depilatory and as a constituent of luminous or phosphorescent paint.

THE UNCOMMON METALS

The Uses of Arsenic.—*The Metal.*—Arsenic is not used industrially in its pure state.

Arsenic Alloys.—Arsenic is not used in alloys.

Arsenic Compounds.—Arsenic disulphide (As_2S_2) is used in tanning and for making fireworks. Arsenic hydride (AsH_3) is known as *arsine*, and it is employed as a delicate indicator in *Marsh's test* for

arsenic; it is also used in organic synthesis and chemical warfare. Arsenous oxide (As_2O_3) is commonly known as *arsenic* or *white arsenic*, and this is still taken occasionally internally by some of the gentler sex to improve their complexions; it does and the undertaker then uses it as an embalming fluid to preserve them from further decay—pending the march to the graveyard. It is also used as a drug by that class of dope fiends known as *arsenic eaters*.¹²

It is a constituent of *Fowler's solution* which is employed in medicine for stimulating the heart. It is also employed in glass making, as a mordant in calico printing, as a rat poison and in taxidermy. Arsenic sulphide (As_2S_3), or *orpiment* as it is called, is used in the arts as a pigment and is sold under the names of *King's yellow* and *arsenic yellow*; a natural sulphide is known as *realgar* and when this is mixed with sulphur and potassium nitrate it makes the famous *Bengal lights*.

The Uses of Beryllium.—*The Metal.*—Beryllium is not used in the industries in its pure state.

Beryllium Alloys.—At present beryllium is used in forming alloys with aluminum and copper and as this is harder and stronger than ordinary aluminum alloys it is used for airplane construction.

Beryllium Compounds.—None of the compounds of beryllium are of any commercial importance. Beryllium oxide (BeO_2) is used as the starting point in making other beryllium salts.

The Uses of Cadmium.—*The Metal.*—Cadmium is

¹² The fatal dose is from 1 to 3 grains but arsenic eaters can take four times that amount and still survive to tell the tale.

used for coating iron and steel articles to make them rustproof. It is also used for the electrodes of *electric standard cells*.¹³

Cadmium Alloys.—The metal is employed as a constituent of alloys having a low melting point or fusible alloys as they are termed.

Cadmium Compounds.—Cadmium acetate ($Cd(OOCCH_3)_2 \cdot 3H_2O$) is used as a reagent for determining sulphur, selenium and tellurium in iron and steel, and it is also used in dentistry. Cadmium chloride ($CdCl_2$) is employed as a reagent for pyridine bases, in photography and in the dye and textile industries.

Cadmium iodide (CdI_2) is used as a reagent for alkaloids and nitrous acids, in photography, and in medicine as an antiseptic and in ointments. Cadmium sulphide (CdS) or *cadmium yellow* or *jaune brillant*,¹⁴ as it is variously called, is used as pigment for coloring soaps and in fireworks and also in ceramics for obtaining yellow and orange glazes. Lastly, cadmium valerate ($Cd(C_5H_9O_2)_2$) is used in medicine as an antispasmodic.

The Non-uses of Columbium.—The metal is not used industrially, and it is not employed as a constituent of alloys and none of its compounds are of commercial importance.

The Non-uses of Germanium.—The metal germanium, like columbium, has no industrial uses, is

¹³ A standard electric cell has a cadmium amalgam ($CdHg$) cathode and a mercury anode while the electrolyte is a solution of cadmium sulphate.

¹⁴ This is French for *yellow brilliant*.

not employed in any useful alloys and its compounds have no industrial applications.

The Uses of Manganese.—*The Metal.*—In its pure metallic state manganese is not used in the industries.

Manganese Alloys.—Manganese steel is very hard and tough and is used for burglar-proof safes, the jaws of rock-crushers and railway switches and crossings. Manganese bronze is remarkable for its strength and toughness, and *manganin*, which is an alloy of copper with a little nickel and a large percentage of manganese in it, is largely used in making standard resistance coils for electrical apparatus because its resistance does not change with moderate changes in its temperature.

Manganese Compounds.—Manganese dioxide (MnO_2), or *battery manganese* as it is sometimes called, is used as an oxidizing agent, in the manufacture of chlorine and other halogens, in electric dry cells and as a depolizer in the Leclanche's cell; in paints and varnishes, in the glass and rubber industries, and medically as a tonic and alterant. Manganic hydroxide ($Mn(OH)_3$) is employed as a pigment for textiles, while manganic sulphate ($Mn_2(SO_4)_3$) is used as a powerful oxidizing agent in the manufacture of synthetic products.

Manganous borate ($Mn_2B_4O_7$) is employed as a drier in paints and varnishes as well as in the making of leather. Manganous chloride ($MnCl_2$) is used in medicine in chlorosis,¹⁵ as an antiseptic in gargles, in dyeing and in the manufacture of glass. Manganous oxalate ($Mn(C_2O_4) \cdot 2\frac{1}{2}H_2O$) is employed in the preparation

¹⁵ Sometimes called *green sickness*. It is a disease to which young women are subject.

of metallic magnesium and as a drier for paints; manganous silicate ($MnSiO_2$) is used in the ceramic and glass industries; finally, manganous sulphate ($MnSO_4$) is used in medicine as a tonic and cathartic, as a mordant in dyeing and in the ceramic and glass industries.

The Uses of Molybdenum.—*The Metal.*—Molybdenum is used for grids in radio tubes in order to keep them from softening.

Molybdenum Alloys.—The metal forms steel-like alloys with carbon and it is used in the form of *ferromolybdenum* to harden steel. It is used for crankshafts and connecting rods, as a support for lamp filaments, as a resistance element in electric furnaces and for other heating devices.

Molybdenum Compounds.—The chief use of molybdenum compounds is as a reagent for testing and estimating phosphoric acid. Molybdic acid (H_2MoO_4) is employed in making an *ammonium molybdate solution*, and as a reagent for testing orthophosphates and the arsenates.

The Uses of Selenium.—*The Metal.*—Metallic selenium is used for making the *selenium cell*¹⁶ and this, in turn, has been used as a *photometer* for measuring the relative intensity of the light of different stars, for *telemechanics* or remote radio control, for *telepictura*, or the radio transmission of pictures, and for *television* or seeing by radio. The selenium cell has now given way to other and far more sensitive

¹⁶ A photoelectric cell which conducts electricity and whose resistance is decreased when it is exposed to light.

light cells. The alloys of selenium and its compounds have no uses outside of the laboratory.

The Uses of Tungsten.—*The Metal.*—Tungsten is not used in the industries in its pure state.

Tungsten Alloys.—Tungsten is alloyed with steel and this is used for high speed steel tools which even when heated red-hot by cutting retain their temper. It is also used for filaments for electric light bulbs and for magnets which are highly permanent.

Tungsten Compounds.—***Sodium tungstate*** ($\text{Na}_2\text{WO}_4 \cdot 2\text{H}_2\text{O}$) is used as a mordant in dyeing and to render muslin fireproof. Tungsten-sodium tungstate ($\text{Na}_2\text{WO}_4 \cdot \text{W}_2\text{O}_5$) is employed as a pigment and is sold under the name of *saffron bronze* and *orange tungsten*. Potassium tritungstate ($\text{K}_2\text{W}_3\text{O}_{10}$, W_2O_5) goes by the name of *violet-tungsten*, a bluish-black powder which is used as a pigment. Tungsten oxychloride (WOCl_4) absorbs moisture from the air and is, in consequence, used as a drier. Finally, tungsten trioxide (WO_3) is used in the manufacture of metallic tungsten for lamp filaments.

The Uses of Tantalum.—*The Metal.*—Tantalum makes possible the trouble-free current rectifier chargers for radio batteries and is used in radio tubes to maintain the vacuum. It is employed as a substitute for platinum for filaments in incandescent lamps and serves as electrodes in the tube of the now familiar brilliant neon signs. The *spinnerets* that are used for spinning the shimmering threads of rayon, that is, artificial silk, are made of tantalum.

As tantalum is practically noncorrosive, chemical apparatus is made of it; for this reason precision instru-

ments for recording time, temperature, humidity, etc., are made of it, and it is also used for pens. Finally, because it takes a high polish and has an iridescent sheen it is being used for the cases of watches. The alloys and compounds of tantalum are not commercially important.

The Uses of Tellurium.—*The Metal.*—Tellurium is not used commercially in its metallic state.

Tellurium Alloys.—There are several natural alloys of tellurium as, for example, that of gold-silver telluride, but they have no industrial uses.

Tellurium Compounds.—There are various compounds of tellurium but none of them are of any practical importance.

The Uses of Thallium.—*The Metal.*—Thallium is not used commercially in its metallic state.

Thallium Alloys.—Thallium and lead can be alloyed in all proportions.

Thallium Compounds.—*Thallium nitrate* ($TiNO_3$) is used as a reagent and indicator and for making green fire for fireworks. *Thallous hydroxide* ($TiOH$) is used for making ozone indicator paper, i.e., paper that turns brown when in contact with ozone; and *thallous oxide* (TiO) which is employed in the manufacture of flint glass and artificial gems.

The Uses of Titanium.—*The Metal.*—It has no use in its metallic state in the industries.

Titanium Alloys.—Titanium is employed as a constituent in four useful alloys and these are (1) ferro-carbon titanium, (2) carbon-free ferro-titanium, (3) cupro-titanium, and (4) mangano-titanium. By adding the ferro-titanium alloys to steel a cleaner and

sounder product is obtained, while the cupro-titanium and manganio-titanium are used as deoxidizers in making brass and bronze ingots.

Titanium Compounds.—Titanium dioxide (TiO_2) is used in the manufacture of arc-lamp electrodes. Under the name of *titanium white* it is sold to compete with white lead and zinc white. Titanium tetrachloride ($TiCl_4$) gives forth great volumes of fumes when it is exposed to the air and it was used for smoke screens during the World War. Titanyl sulphate ($TiOSO_4$) and titanyl nitrate ($TiO(NO_3)_2$) are generally of a violet or green color and these form powerful mordants which produce brilliant and stable colors.

The Uses of Vanadium.—*The Metal.*—Vanadium is used in its metallic state as a catalyst.

Vanadium Alloys.—An iron and vanadium alloy known as *ferrovanadium* is used in making vanadium steel.

Vanadium Compounds.—The three chief compounds of this metal are vanadium oxide (V_2O_5), and this is used as a mordant in dyeing, in the manufacture of steel and of silver vanadate (Ag_3VO_4) and this, in turn, is used as a catalyst, and vanadyl trichloride ($VOCl_3$) which is used as a mordant in the dyeing industry.

The Uses of Zirconium.—*The Metal.*—Zirconium is not used in the industries in the metallic state.

Zirconium Alloys.—The metal itself or an alloy of ferro-silicon zirconium is used in making various steels and for filaments for incandescent lamps.

Zirconium Compounds.—Zirconium oxide (ZrO_2) is used for making incandescent gas mantles, for mak-

ing enamels, glazes for glass, in the ceramics, in medicine, in X-ray photographic work and as a substitute for bismuth salts.

THE RARE EARTH METALS

The Uses of Cerium.—*The Metal.*—Cerium is not used industrially in its metallic state.

Cerium Alloys.—Cerium is used for alloys employed in making gas lighters and in other pyrophoric and spark-producing alloys.

Cerium Compounds.—Compounds of cerium and those of a few of the other rare earth metals of the cerium group are largely used for making incandescent gas mantles. Ceric ammonium nitrate ($Ce(NO_3)_4 \cdot 2NH_4NO_3$) is the starting point in the preparation of pure cerous salts. Ceric sulphate ($Ce(SO_4)_2 \cdot 4H_2O$) is used in photography and in analytical chemistry as an oxidizing agent.

Cerous ammonium nitrate ($Ce(NO_3)_3 \cdot 3NH_4NO_3 \cdot 10H_2O$) is employed in making gas mantles, as is cerous carbonate ($Ce_2(CO_3)_3 \cdot 5H_2O$). Cerous hypophosphite ($Ce(H_2PO_2)_3 \cdot H_2O$) is used medicinally in phthisis. Cerous nitrate ($Ce(NO_3)_3 \cdot 6H_2O$) is employed in making gas mantles. Cerous oxalate ($Ce_2(C_2O_4)_3 \cdot 9H_2O$) is the starting point in the preparation of other rare earth oxides, and also in medicine as a tonic and sedative. Finally, cerous sulphate ($Ce_2(SO_4)_3$) is used in making aniline black.

The Uses of Yttrium.—*The Metal.*—Yttrium as a metal has no commercial applications and there are no alloys in which it is used.

Yttrium Compounds.—Yttrium oxide (Y_2O_3) in its

natural state contains the salts of all of the other yttrium group of metals and it is, therefore, used as the starting point for extracting them. A few of the salts of yttrium are used in making gas mantles. Other than this industrial application yttrium salts and those of the yttrium group of metals have only a scientific value.

THE RADIOACTIVE METALS

The Uses of Radium.—The Metal.—Radium in its pure metallic state has no commercial uses. It has been and is, however, of enormous value to science in that it has (1) enabled us to calculate the exact weight of molecules; (2) to conclude that atoms of whatever kind are built up of a nucleus of positive electric charges called protons, and around which are negative electric charges called electrons.

(3) It is of further importance in that the heat given off by the disintegration of the radium in the crust of the earth is quite enough to maintain its present temperature; (4) that the disintegration energy which is released by the radioactive elements makes it possible to calculate (a) the age of the earth, and (b) the long period in which life has existed on the earth; and, finally (5) the transformation of one element into another.

Radium Compounds.—All of the following radium compounds are used in medicine for the treatment of cancer and other malignant growths and for making all ordinary radioactive experiments.

Radium bromide ($RaBr_2$) when sold in the open market is usually mixed with barium bromide ($BaBr_2$);

radium carbonate ($RaCO_3$) is usually mixed with barium carbonate ($BaCO_3$); radium chloride ($RaCl_2$) is usually mixed with barium chloride ($BaCl_2$); and, finally, radium sulphate ($RaSO_4$) is usually mixed with barium sulphate ($BaSO_4$).

Radioactive paint, or *luminous paint* as it is also called, is usually formed of any of the above named radioactive salts mixed with the sulphide of calcium, barium and zinc. It is used as a paint for watch dials, door knobs, keyholes, electric pendants and switches and signs.

Radio-luminous material is a preparation made with one of the above named radium salts and phosphorescent zinc sulphide and it is used as a luminous paint for the purposes just cited. It is put up in $\frac{1}{2}$ grain vials and sells for \$5.00; you can get it of Eimer and Amend, 18th Street and Third Avenue, New York City.

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